Manuscript Details

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Title	Correlation between building characteristics and associated energy use intensity: Prototyping low-rise office buildings in Shanghai
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Abstract

The enormous building energy consumption in Shanghai necessitates the identification of standard buildings to offer guidance for the adequate design of retrofitting strategies in order to promote a sustainable built and architectural environment. In this regard, this study develops a methodological approach to establish prototypical buildings using performance index system (PIS) founded on an on-site survey. Emphasis is focused on low-rise office buildings in Shanghai. A total of 10 office parks containing 136 single low-rise office buildings in Min Hang District were systemically selected for survey and data collection. The proposed PIS includes building orientation, number of floors, window/wall ratio, heat and cold source type, plan form, and construction year. Using cluster and correlation analysis, the surveyed buildings are classified based on the impact of each PIS on the annual building energy use intensity. Based on this approach, the most influencing indexes are construction year, the number of floors, window-wall ratio and building orientation. This result refines the surveyed building samples to four prototypical buildings as representative standards for low-rise office buildings. Subsequently, typical buildings representing each of the prototypical buildings were defined. The stipulated approach provides a systematic framework for building classification, characteristic-based evaluation of building energy performance and identification of key performance index for building retrofit purposes.

Keywords	Low-rise; Office building; prototypes; PIS; Shanghai.
Taxonomy	Architectural Engineering, Energy Application
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Submission Files Included in this PDF

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29th August 2019

Dear Editor,

Cover Letter

I am now submitting the manuscript re-entitled "**Correlation between building characteristics and associated energy use intensity: Prototyping low-rise office buildings in Shanghai**" for publication in the Journal, Energy and Buildings, on behalf of the other co-authors.

The enormous building energy consumption in Shanghai necessitates the requirement for adequate measures to promote a sustainable built and architectural environment. Due to the vast distribution of low-rise office buildings in this city, this study aims at the identification of prototypical low-rise office buildings to guide the development of energy-efficient and low-cost retrofit strategies. As such, the performance index system (PIS) founded on the building characteristics obtained from surveyed low-rise office buildings were established. The proposed PIS adopted in this study included building orientation, number of floors, window/wall ratio, heat and cold source type, plan form, and construction year. A total of 10 office parks containing 136 single low-rise office buildings in Min Hang district of Shanghai was selected for on-site survey and data collation. Using cluster and correlation analysis, the surveyed buildings are classified based on the impact of the PIS on the annual building energy use intensity. Based on this, four typical buildings representing each of the prototypical buildings were defined as standard buildings for low-rise office buildings in Min Hang district of Shanghai. This stipulated methodology for identifying prototypical buildings via PIS provides a systematic framework for building classification and identification of key performance index for pre-design stage for energy-efficiency of buildings and key index which affect the energy efficiency of building retrofit purposes in practice.

The appropriateness of the collection, analysis and interpretation of obtained data have been carefully checked. The article is ORIGINAL and unpublished elsewhere. I would be most grateful to receive feedback about your decision to publish the paper in Energy and Buildings Journal once you have had the reviewers' comments.

Best Regards,

Yuanda Hong

Feedback to Editors and Reviewers

Comments from the editors and reviewers:

Reviewer 1

The manuscript has been improved greatly according to reviewers' comments, and response to comments have been answered accordingly.

Response: The authors sincerely appreciate and acknowledge the reviewer for the accorded improvement in this manuscript.

Revisions on the current manuscript was based on the reviewer's comment. Response to the comment is presented below. The revisions made on the manuscript pertaining to the comment are presented after the response to the comment (in *Italics*). Also, the revisions are highlighted in the revised manuscript for adequate track audit.

Comment 1:

Since specific HVAC system, ventilation method, working hour schedule were considered and used in the computation and analysis process, it was strongly suggested that the author mentioned this in the limitation of this research section.

Response: Thanks for the suggestion. Accordingly, limitations involving the considered HVAC system, ventilation method and working hour schedule are included in the manuscript (Section **5. Conclusion and future research directions**). The revised section is shown below:

> Revised version: '***Limitation and future development***
> *In this study, a thorough assessment of the HVAC system, ventilation mechanism and varying working hour schedule was not conducted due to the limited preferences in China's building standards. Also, the building management and control index was not considered in the building prototype identification. These indexes were assumed on a general perspective across all building samples. In order to improve the efficacy of the methodology, further analysis incorporating specific details of these indexes is suggested.*'

Reviewer 2

The manuscript still contains too many references to information contained in the supporting document that is not published. These references must be avoided and the manuscript must contain all the relevant information. A major review of the manuscript is necessary to address this problem.

Response: The authors appreciate the reviewer for the opportunity to further revise the manuscript for better comprehension. Also, we acknowledge the reviewer's impact to the accorded improvement of this manuscript.

Revisions on the current manuscript was based on the comment above. Revisions made on the manuscript pertaining to the comment are presented after the response to the comment. Also, the revisions are highlighted in the revised manuscript for track audit.

First, the authors appreciate the reviewer for the suggested comment. Thanks to your suggestion, references to information contained in the supporting document have been all removed. If needed, such information was added in the manuscript. All relevant information in the supporting document including Tables S1, S2, S4, S5, S6 and S7, are now included in the manuscript as Tables 2, 3, 5, 9, 10 and 13, respectively. Table 9 and 10 present the building characteristics of surveyed low-rise buildings using Hong Xing International Square and Cao He Jing office park as examples. The remaining data presented in the supporting document is: 1) details of the measuring device and measured data for evaluating and validating the simulated building energy consumption (Tables S1-S4 and Fig. S1); 2) proposed prototype models for IES-VE software simulation (Table S5), and 3) a summary of all surveyed low-rise office building (Table S6 and S7). This information is aimed to provide credibility to this research, and would not affect the manuscript's coherence and readers' comprehension.

Besides, the manuscript and supporting document have been revised to update the captions of the figures and tables, as well as revising the related discussion in the content of the manuscript. Also, adequate references for all surrogate data sources were included.

Kindly find below changes made in the revised version of both the manuscript and the supporting document.

> Revised version: '*2.1.5. Window/wall (W/W) ratio…Description of the standard thermophysical characteristics for external building components regarding different W/W ratio is presented in Table 2.*

Table 2. Summary of envelope thermal property with respect to window/wall ratio and construction year [1].

	External curtain wall (window/wall ratio)	**Overall Heat transfer coefficient ($W/m^2.K$)**		**Model thermal Property (C2 model) ($W/m^2.K$)**	**Model thermal property (C1 model) ($W/m^2.K$)**
		GB50189-2005	GB50189-1980	GB50189-2005	GB50189-1980
Roof		≤ 0.70	1.5	0.2714	3.1532
Wall (non-transparent curtain wall)		≤ 1.0	2	0.2451	2.4370
Exterior floor		≤ 1.0		0.2730	2.2183
External curtain wall	≤ 0.2	≤ 4.7	6.4	1.6	5.4380
	0.2-0.3	≤ 3.5	6.4		
	0.3-0.4	≤ 3.0	6.4		
	0.4-0.5	≤ 2.8	6.4		
	0.5-0.7	≤ 2.5	6.4		
Roof (transparent part)	≤ 0.02 (with exterior shading)	≤ 3.0			
	0.021-0.05	≤ 3.0			
	≤ 0.02 (without exterior shading)	≤ 3.0			
	0.021-0.05	≤ 3.0			
Floor (thermal resistance)		$R \geq 1.2\ m^2.K/W$		1.9987	3.3264
Underground exterior wall (thermal resistance)		$R \geq 1.2\ m^2.K/W$			

…

2.3 Computational simulation*…The adopted regulations for simulating the HVAC system and the human comfort requirements during the working periods are presented in Table 3..., respectively.*

Human density was based on "Design Standards for energy efficiency of public buildings" [1]. The regulated average personal area of open office space is 4 m^2/person. Before 2005, lighting density was 25 W/m^2 and was reduced to 11 W/m^2 in 2005 regulation. Moreover, equipment density is 20 W/m^2. According to regulation [2], a modulating percentage was assigned in the simulation of daily human density and utilization of lighting and equipment systems. Typically, there are no human inside the building from 0:00 - 07:00 and 20:00 - 24:00. Hence, utilization of equipment will be 0%. From 8:00 - 9:00, people arrive at office and it is assumed that utilization of equipment is 50%. During the working period from 9:00 – 12:00 and 14:00 – 18:00, utilization will be 95% according to regulation. At lunch time (12:00 – 14:00), utilization will be 80%. Lastly, at closing hour (18:00 – 20:00), utilization will be 30%.

Table 3: Regulation for HVAC System [1, 3]

HVAC parameter	***Value***
Refrigerator COP	*5.5*
Energy efficiency ratio	*3.2*
Fan efficiency	*0.7*
Fresh air	*8.3L/s/person*
Fresh air temperature (^oC)	*14*
Indoor design temperature (^oC):	
- summer	*22 - 28*
- winter	*16 - 22*
Infiltration	*0.2 ACH in perimeter area, 0 ACH in internal area*

3. Results and discussion

3.1 Data collection

Shanghai has 16 districts…, each with a different share of non-residential building types and ranking (Table 5)… From Table 5, Pu Dong and Min Hang district are the first and second largest in terms of non-residential buildings with 14,013 and 6,414 m^2 building area.

Table 5. Summary of non-residential buildings and office buildings in Shanghai [4].

District	***Non-Residential Buildings (10^4 m^2)***	***Non-Residential Buildings Area Rank***	***Land Area (km^2)***	***Offices Area (10^4 m^2)***	***Volume ratio (Density)***
Total	*62 231*		*6340.50*	*8 150*	*0.09*
Pu Dong New Area	*14 013*	*1*	*1210.41*	*1 777*	*0.12*
Huang Pu	*2 035*	*13*	*20.46*	*758*	*0.99*
Xu Hui	*2 755*	*9*	*54.76*	*773*	*0.50*
Chang Ning	*1 724*	*14*	*38.30*	*585*	*0.45*
Jing an	*2 644*	*10*	*37.37*	*724*	*0.71*
Pu Tuo	*2 331*	*12*	*54.83*	*519*	*0.43*
Hong Kou	*1 410*	*15*	*23.48*	*448*	*0.60*
Yang Pu	*2 532*	*11*	*60.73*	*484*	*0.42*
****Min Hang***	*6 414*	*2*	*371.68*	*501*	*0.17*
Bao Shan	*4 227*	*5*	*270.99*	*290*	*0.16*
Jia Ding	*4 836*	*4*	*458.80*	*451*	*0.11*
Jin Shan	*3 081*	*8*	*586.05*	*159*	*0.53*
Song Jiang	*5 738*	*3*	*604.71*	*230*	*0.09*
Qing Pu	*3 780*	*6*	*675.54*	*164*	*0.06*
Feng Xian	*3 677*	*7*	*687.39*	*208*	*0.05*
Chong Ming	*1 033*	*16*	*1185.49*	*79*	*0.01*

**District selected for sampling*

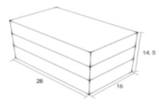
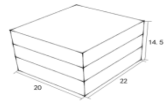
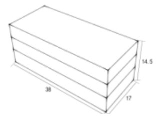
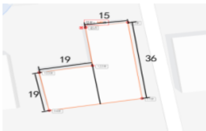
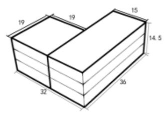
…

Taking Hong Xing International Square and Cao He Jing office park for examples of C2 and C1. Tables 9 and 10 present the specific building characteristics of the surveyed low-rise office buildings built within C2 and C1, respectively.

…

Simulation validation was conducted by comparing simulated energy results for prototypes C1B1 and C2B1 with actual metered data from the representative buildings. Simulated results were observed to be above 95% similar to actual data and demonstrate that the simulation tool is reliable for this study (Table 13).

Table 9. Specific building characteristics of selected low-rise buildings built within 2006-2015 (All dimensions are in metric units).

Office park name	*Hong Xing International Square*								
Building number		*Length*	*Width*	*Height*	*Number of Floors*	*Floor Area*	*Actual photos*	*Simplified building model*	*Amount*
1.3.5.6.7.8.9.10.12.14.15.16.18.19.20.21.22.23		*28*	*16*	*14.5*	*3*	*1344*			*18*
2.4		*22*	*20*	*14.5*	*3*	*1320*			*2*
24.25.26.27.28.29.30.31		*38*	*17*	*14.5*	*3*	*1938*			*8*
13.17		*36*	*32*	*14.5*	*3*	*2748*			*2*

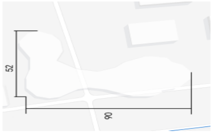
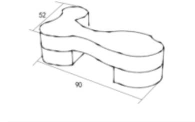
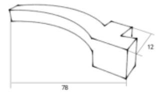
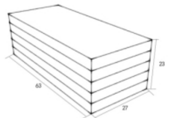
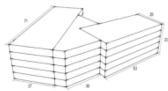
11		90	52	14.5	3	2575			1
32		78	12	14.5	2	1550			1

Table 10. Specific building characteristics of selected low-rise buildings built within before 2005 (all dimensions are in metric units).

Office park name	Cao He Jing Office Park								
Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
2.3.4.5.6.7.8.9.10. 11.12		63	27	23	5	8550			11
1		71	27	23	5	21225			1

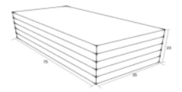
13		75	35	23	5	13125			1

Table 13. Comparison of actual with simulated energy consumption for prototypes C2B1 and C1B1

Building	***Prototype***	***Building floor***	***Actual energy consumed (kWh/yr)***	***Simulated energy consumed (MWh/yr)***
Building 60 in Hong Xing Int'l Square	*C2B1*	*2 and 3*	*113,921.30*	
		1	*42,309.74*	
		Total	*156,231.04*	*164.0 (95%)*
Building 1 Fawkes Chain Business Building (Chun Shen Road)	*C1B1*	*2*	*89,626.07*	
		1	*80,382.26*	
		Total	*170,008.33*	*176.5 (96%)*

References

1. MOHURD, *Public Building Energy Saving Design Standard*, *GB-50189*. China National Code, 2005.
2. MOHURD, *Design standard for energy efficiency of public buildings GB50189-2015*, Ministry of Housing and Urban-Rural Development of the China, Editor. 2015: China.
3. MOHURD, *The minimum allowable values of the energy efficiency and energy efficiency grades for unitary air conditioners*, *GB-19576-2004*, M.o.H.a.U.-R. Development, Editor. 2005: China.
4. Bureau, S.M.S., *Shanghai Statistical Yearbook 1980-2017*, S.M.S. Bureau, Editor. 2017: Shanghai.

Correlation between building characteristics and associated energy consumption: Prototyping low-rise office buildings in Shanghai

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Abstract

The enormous building energy consumption in Shanghai necessitates the identification of standard buildings to offer guidance for the adequate design of retrofitting strategies in order to promote a sustainable built and architectural environment. In this regard, this study develops a methodological approach to establish prototypical buildings using performance index system (PIS) founded on an on-site survey. Emphasis is focused on low-rise office buildings in Shanghai. A total of 10 office parks containing 136 single low-rise office buildings in Min Hang District were systemically selected for survey and data collection. The proposed PIS includes building orientation, number of floors, window/wall ratio, heat and cold source type, plan form, and construction year. Using cluster and correlation analysis, the surveyed buildings are classified based on the impact of each PIS on the annual building energy use intensity. Based on this approach, the most influencing indexes are construction year, the number of floors, window-wall ratio and building orientation. This result refines the surveyed building samples to four prototypical buildings as representative standards for low-rise office buildings. Subsequently, typical buildings representing each of the prototypical buildings were defined. The stipulated approach provides a systematic framework for building classification, characteristic-based evaluation of building energy performance and identification of key performance index for building retrofit purposes.

Keyword: *Low-rise, Office building, prototypes, PIS, Shanghai.*

1. Introduction

Shanghai is the largest industrial and populous city in the hot summer and cold winter (HSCW) climate zone of China. Extending 120 km from south to north, and 100 km from east to west, Shanghai has an urban population density of 6000/km^2 as at 2017 [1-4]. The broad climate variance scope of this city requires buildings to meet with anti-overheating, ventilation, and cooling requirements in summer, while anti-cold and heating requirements are also expected in winter. Consequently, this has resulted in the high building energy consumption within this city [3, 5-7]. Moreover, with the estimated rate of economic growth, building energy consumption is envisaged to grow exponentially [8, 9]. Commercial buildings, particularly office buildings, are considered as the most energy-consuming due to the intensity of activities carried out within the buildings [10-12]. Therefore, promoting sustainable office buildings in this city is required.

To promote a sustainable architectural and built environment, it is necessary to develop energy conservative measures (ECMs) for the different building typologies. Prior to the development of these measures, analytical studies on existing building stocks with an emphasis on the effect of building characteristics on the energy consumption need to be conducted. Prominent approach to determine this effect includes simulated building analysis [12-15]. For simulation purposes and further studies, it is imperative to develop prototypes that suitably represents existing building stocks and its characteristics.

However, developing prototypical buildings depends on the available data and statistics of existing building stocks, which also determines the approach to be adopted. In the circumstances with unavailable and scarce information, cluster analysis approach is considered for its inherent merits. This approach involves the grouping of variables so that the variables in a group are similar (in some sense) to each other than those in other groups. Clustering approach is widely used in the building energy analysis, such as determining characteristic occupancy patterns [16-18], load profiles [19-21], core building energy factors [22, 23], energy performance benchmarking [24] and prototypical buildings [25]. The latter uses agglomerate hierarchical clustering (AHC) of building performance index to define typical buildings able to represent the surveyed residential building stocks within Hangzhou city in Zhejiang Province of China. Nonetheless, China still lacks region-oriented information of prototypical building for building energy research studies, particularly for commercial building typology.

1.1 Review of prototypical studies on commercial building typology

Building prototypes are devised to model existing buildings and their attributes by means of a system of performance indexes. The prototypical buildings serve as an initial platform for evaluating building design, ECMs, and other analytical studies, such as energy market evaluation and policy-making [26, 27]. The performance index systems (PIS) required to determine building prototypes include building typology and their corresponding data that describes the building characteristics [28, 29]. Necessary data for this purpose were acquired from a site survey (small or large-scale survey) of existing buildings within a particular region.

A building's shape and HVAC characteristics, as well as other factors influencing energy consumption, such as internal ambiance, building facilities, occupancy pattern and requirements, and geometric orientation, are relevant in describing a suitable prototypical building. However, the use of all these indexes to establish a prototypical building requires rigorous and complex analysis. Hence, for simplification, construction period, building type and size, and HVAC systems characteristics are the most commonly used indexes [26, 30]. The other indexes are mostly applied in the design and evaluation of building retrofit measures, which takes part after the establishment of the building prototypes [31].

Monteiro *et al.* [32] used the construction year and building shape characteristics as indexes for the identification of archetypical buildings. These indexes are the base criteria established in the TABULA (Typology Approach for Building Stock Energy Assessment) project for defining building prototypes [31]. The TABULA project suggests that building classification should be founded on the climatic area, building age class and building size class [33]. Moreover, the heat supply system should also be considered for adequate assessment of the building energy performance, particularly for *ex-post* and *ex-ante* evaluation of retrofit measures [31]. Ye *et al.* [26] adopted the weather features, building geometry, envelope, HVAC system type, schedule and internal load to create prototypes for religious buildings. Li et al. [34] described the building geometry to include the window-wall ratio (WWR), building height and aspect ratio (L/M, L = length and M = width).

Before the evaluation of building retrofit measures, basic statistics accounting for the frequencies of building types and heat supply systems are pre-requisites for the design of building prototypes. Based on the availability of these statistics, three different methodological approaches are defined: "Real Example (ReEx) Building", "Real Average (ReAv) Building", and "Synthetical Average (SyAv) Building" [33]. The ReEx approach adopts experts' experience in the absence of statistical data to identify the building prototypes. On the other hand, the ReAv approach uses the mean statistical data of geometrical and construction features from a large-scale building survey to identify the archetypical building. In the SyAv approach, the prototypical building is a virtual building characterized by a statistical composite of the features detected in a class of buildings from a large building sample. The latter is commonly used in the circumstances with limited data availability or relatively great difficulty with acquiring data.

Retrospectively, building data statistics for developing prototypes were collated from small-scale survey of existing buildings. The first prototypical buildings were developed by Synergic Resource Corp using data from a small-scale survey in the 1980s to study the effect of occupancy on building energy consumption [35]. Also, this survey type was adopted to provide prototypical buildings as a benchmark for energy performance for non-domestic buildings in Ireland [36]. Nonetheless, the developed prototypes from a small-scale survey may not accurately and realistically represent the entire building stocks within the given region. This limitation has promoted the need for large-scale survey in developing building prototypes.

Large-scale surveys are more extensive and have a broader coverage of the sampled buildings, which tends to provide more specific prototypical buildings. Commercial building benchmark prototypes that adopted this survey type are listed in the literature [37, 38]. One major challenge of the large-scale survey is that a higher number of existing buildings make further analysis complex and challenging [39]. However, the selection of a reasonable range of existing buildings is essential to ensure a specific and accurate survey. A key selection criterion is that the randomly selected buildings based on a specific variable should exhibit the same proportion to that of the actual ratio.

1.2 Building typology in Shanghai, China

To develop energy-efficient measures, it is common practice to design prototypes for the most prominent existing building typologies. The design of prototypical buildings is typical for each geographical region and represents limited types of buildings within that region [26]. Focusing on Shanghai, office buildings account for more than 25% of the existing commercial building stocks [4]. Moreover, office buildings in Shanghai comprise of over 50% low-rise office building blocks. This type of commercial buildings has unique characteristics in terms of functions and building systems, which contribute a significant share in building energy consumption. Therefore, it is significant to develop prototypes that will serve as a guide to develop energy-efficient measures for low-rise office buildings in Shanghai.

Among the reviewed reference buildings developed in previous studies in China, there are limited studies conducted for office building blocks [2]. All studies were based on a small-scale survey and without a broad coverage of building samples. Specifically, there are no typical building model prototypes for existing low-rise office buildings in Shanghai at present. To fill this gap, this study proposes an approach to develop prototypical buildings for existing Shanghai low-rise office buildings employing large-scale survey. The establishment of this prototypical reference buildings will aid building owners, practitioners, and stakeholders understand building dynamics, evaluate and compare variations in building energy performance pertaining to their characteristics.

1.3 Research gaps and aims

As discussed earlier, the low-rise office buildings have a dominant share in the building energy consumption in Shanghai city. Therefore, low-rise office building typology was selected to represent the building stocks in Shanghai for the establishment of prototypical buildings. By so doing, the relationship between building characteristics and energy consumption is required. As such, this study aims at:

- to obtain the energy consumption for existing low-rise office building typologies via metered and simulated data,
- to correlate the building energy consumption with the existing low-rise office building characteristics, and
- to develop prototypes for existing low-rise office buildings using the major building characteristics from correlation and cluster analysis.

This study is based on the survey of existing low-rise office building blocks in Min Hang district, Shanghai. A survey involving 10 office parks with 136 randomly selected office buildings in this district was conducted.

2. Methodology for developing low-rise office building typologies in Shanghai

Generally, methodologies for developing low-rise office building prototypes require the definition of selected sample buildings characterized by their geometrical, thermo-physical features, and so on [40, 41]. The procedure for developing a reasonable low-rise office building prototypes consist of four main steps, as illustrated below:

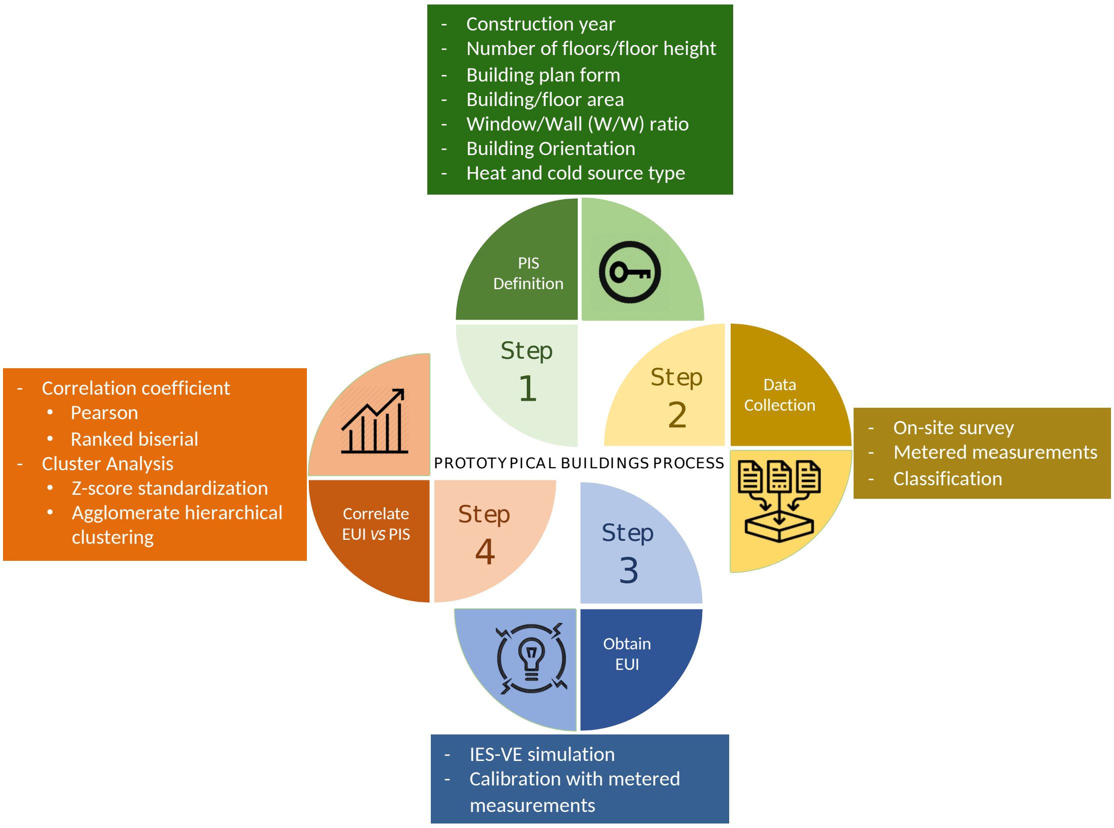


Fig. 1. Proceed for building prototype establishment

- **Step 1:** Definition of PIS to develop the relevant building prototype in the specific region.
- **Step 2:** Collation and processing of data collected from site survey and surrogate databases. Also, the classification of the surveyed low-rise office buildings using the defined PIS
- **Step 3:** Simulate and obtain the building energy consumption/energy use intensity (EUI) using the average statistical data of the building characteristics and measured simulation parameters. Here, the building energy consumption is based on the annual electricity consumption for heating, cooling and lighting [34, 42].
- **Step 4:** Statistical analysis of selected low-rise building stocks by performing the correlation between the building PIS and associated energy consumption/EUI. This step will aid in defining key PIS for the establishment of the prototypical buildings.

2.1 Proposed PIS of building energy consumption

The proposed PIS necessary for developing a building prototype are listed in Table 1. The effect of PIS was developed based on their impact on the building energy consumption/EUI. The selected indexes are based on the core attributes that describes the building characteristics, as discussed in Section 1.1. Emphasis was mainly on the building characteristics and not on other additional factors such as occupants' regime and behavior (including working overtime) or building equipment and facilities. This was aimed to reduce simulation complexities and comparison difficulties. These additional factors will broaden the variance in comparison, thus making it difficult to establish collective building prototypes. However, these factors were considered in subsequent studies involving the establishment of suitable retrofitting measures.

In this study, the PIS was limited to the regional architectural and environmental typologies, which includes building orientation, the number of floors, window/wall ratio, heat and cold source type, plan form and construction year. Due to the difficulty with access of data, as supported by ref. [26], data on building schedule, internal loading (occupant, lighting and equipment density) and detailed components of the HVAC systems were assumed to be constant using building standards and regulations from the Chinese government [43, 44]. Further details on these parameters are discussed in Section 2.3.

Table 1: Classification of low-rise office building prototypes

Classification	Core Indexes
Building Characteristics	- *Construction year* *(Building structure and thermophysical properties)* - *Number of floors/floor Height* - *Building plan form* - *Building area/Floor area* - *Window/wall ratio* - *Building orientation* - *Heat and cold source type*
Building Management and Control	- *Office Schedules and Activities* - *Human/Equipment/Lighting Density* - *Human Comfort Requirement*

2.1.1. Construction year (Building structure and thermo physical properties)

Buildings constructed within the same period usually demonstrate similar features and thermal property, particularly when backed up by government policies. Therefore, it is logical to use the construction year to categorize different architectural typology. In 2005, the Ministry of Construction and Urban Planning institute issued "Design standard for energy efficiency of public building", and mandated buildings are built to achieve 50% energy reduction compared with buildings built with 1980 standards. The updated edition, "Design standard for energy efficiency of public buildings GB 50189-2015", was released in 2016 and anticipates that new buildings reach 65% energy reduction of 1980's baseline [43, 44].

Considering the release year of these design standards and the time frame for building construction and implementation of these standards, buildings were categorized into the construction years: before 2005, 2006 - 2015 and after 2016. Nonetheless, buildings built after 2016 are considered to have attained the regulation standards; hence does not require retrofitting measures. Therefore, this study focused on the two construction years: before 2005 (C1) and between 2006-2015 (C2). For emphasis, buildings in C1 and C2 were mainly built with brick or frame structure and concrete, respectively.

2.1.2. *Number of floors/floor height*

The number of floors is categorized based on the China Design Code for Office Building JCJ67-2006 [45]. According to this code, low-rise office buildings are considered to have heights below 24 m (or 1 – 6 floors according to the "Standard for energy consumption survey of civil buildings" [46]).

2.1.3. Building plan form

Another essential building characteristic is the building plan form [47, 48]. In order to ensure practical and accurate classification, three simplifying strategies were considered. First, all insignificant minor details such as surface articulation, attached features, and balconies were ignored. Second, buildings with complicated forms were virtually disassembled into smaller parts of simple forms, and these forms were considered separately. Finally, building forms should be represented parametrically by their plan dimensions of depth, length, and height (20). However, given that height has been earlier considered, the plan dimensions were limited to plane shapes, particularly square (S) and rectangular (R) shapes. Irregular building plane shapes that cannot be disassembled and represented parametrically were considered as other forms. In terms of the entire interior space, vertical traffic containing stairs or lift was ignored for low-rise office typology, because of their insignificant effect on the energy usage of low-rise office buildings

2.1.4. Building area/floor area

This building feature is another parameter that affects the building energy consumption, carbon emissions guide, and indoor thermal environment. The average floor area per building is selected as the primary form of floor area. The building area equals to the floor area multiplied by the number of floors. Here, the floor area is an exact estimate of obtained from the on-site measurement of the building dimension.

2.1.5. Window/wall (W/W) ratio

The window/wall (W/W) ratio is defined as the ratio of glazing area to floor area (G/F) of the building. Depending on the building characteristics and function, the W/W ratio might be disadvantageous to the building energy usage. Specifically, a large W/W ratio will gain extra heat in summer and lose additional heat during winter. As such, this index needs to be considered in defining prototypical buildings with consideration to the thermal properties of external building components. The classification of these indexes is based on GB50189-1980 for buildings before 2005 and GB50189-2005 for buildings after 2005. Description of the standard thermophysical characteristics for external building components regarding different W/W ratio is presented in Table 2. Based on these standards, the W/W ratio was classified into three groups: < 0.2 , 0.2 – 0.4, and > 0.4.

2.1.6. Building orientation

As building orientation has certain particular on the energy efficiency of buildings, this parameter was also considered as a performance index. In this study, the selected building orientations are limited to north-south (NS), 45^{o} south-east (S45^{o}E) and east-west (EW).

2.1.7. Heat and cold source type

The heat and cold sources have the most substantial contribution to building energy consumption and the most significant means of improving the thermal comfort of buildings. According to the distribution method of heat and cold sources, the indexes are divided into two types: decentralized and centralized.

Table 2. Summary of envelope thermal property with respect to window/wall ratio and construction year [43].

	External curtain wall (window/wall ratio)	Overall Heat transfer coefficient ($W/m^2.K$)		Model thermal Property (C2 m odel) ($W/m^2.K$)	Model thermal property (C1 model) ($W/m^2.K$)
		GB50189-2005	GB50189-1980	GB50189-2005	GB50189-1980
Roof		≤ 0.70	1.5	0.2714	3.1532
Wall (non-transparent curtain wall)		≤ 1.0	2	0.2451	2.4370
Exterior floor		≤ 1.0		0.2730	2.2183
External curtain wall	≤ 0.2	≤ 4.7	6.4	1.6	5.4380
	0.2-0.3	≤ 3.5	6.4		
	0.3-0.4	≤ 3.0	6.4		
	0.4-0.5	≤ 2.8	6.4		
	0.5-0.7	≤ 2.5	6.4		
Roof (transparent part)	≤ 0.02 (with exterior shading)	≤ 3.0			
	0.021-0.05	≤ 3.0			
	≤ 0.02 (without exterior shading)	≤ 3.0			
	0.021-0.05	≤ 3.0			
Floor (thermal resistance)		$R \geq 1.2$ $m^2.K/W$		1.9987	3.3264
Underground exterior wall (thermal resistance)		$R \geq 1.2$ $m^2.K/W$			

2.2 Sampling methodology

Vital performance data are collated from an on-site survey and analyzed to evaluate EUI using the Integrated Environmental Solutions Virtual Environment (IES-VE) simulation software. The survey was supported with GIS information retrieved from reliable online database, Baidu and Anjuke website. Anjuke Group is a distinguished real estate information service group that has branches in 31 cities. Its monthly independent access to the website has exceeded 69 million users. The data collection period is from August to October 2018.

Due to the difficulty in obtaining valuable data for all buildings, a simple random sampling method was used to select the building samples. The simple random sampling method is a miniature version of the population in which each element has the same probability of selection. The sampling fraction approach (denoted by $f = \frac{n}{N}$, where n is the size of the sample and N is the size of the population) was used to select the building samples [49]. Given that the construction year is the most accessible data, the buildings were randomly selected so that the ratio of the buildings across the construction years are similar to the actual building ratio across the same construction years.

2.3 Computational simulation

IES-VE simulation software was adopted to assess the annual electricity consumption for heating, cooling and lighting for the proposed prototypes. One-year simulation period with a monthly baseline model calibration was used. The simulation used the measured climatic data from low-rise office buildings within the considered construction years. The obtained simulation results are matched with the metered energy consumption data. The result also serves as a guide to provide energy statistics for buildings without energy data.

Data on building schedule, internal loading (occupant density, lighting and equipment density) and detailed components of the HVAC systems were set with reference to the Chinese building design standards and regulations [43, 44]. Due to limited data, these factors were assumed to be constant across the surveyed building samples, coupled with the aid to reduce analytical complexities. Typically, office operation days are about 200-250 days per year except for weekends and holidays. According to an average of 9 working hours per day including an hour lunch-break (09:00 – 18:00 hr), the operating time of each equipment and lights are about 1800-2250 hours per year. Concerning overtime, this varied significantly for different occupants in each building samples surveyed, and as such poses building classification challenges. Hence, for simplicity purpose, the building power consumption was assessed without consideration to working overtime.

The HVAC systems operate at a 50% capacity an hour (08:00 – 09:00 hr) prior to the working period and at full capacity during the office working hours (09:00 – 18:00 hr). Cooling is required around the summer period, which was assumed to be from May 1st to October 30th. Heating is required during the late autumn, throughout winter and early spring periods, which is assumed to be from November 1st to April 30th.

The implemented HVAC type was based on 'Public Building Energy Saving Design Standard, GB-50189' [43] and 'The Minimum Allowable Values of the Energy Efficiency and Energy Efficiency Grades for Unitary Air Conditioners, GB-19576-2004' [50]. This research focuses on existing low-rise office buildings completed before 2005 and between 2005 and 2014 in Shanghai. In these time periods, HVAC systems with constant air volume (CAV) air conditioning module is widely used and COP of 5.5 is recommended for low-rise office buildings according to the GB50189-2005 regulation. Also, the energy efficiency ratio (EER) of 3.2 is used according to the GB 19576-2004 regulation. A passive ventilation mechanism of opening the window was also adopted in the model simulation. The adopted regulations for simulating the HVAC system and the human comfort requirements during the working periods are presented in Table 3 and Table 4, respectively.

Human density was based on "Design Standards for energy efficiency of public buildings" [43]. The regulated average personal area of open office space is 4 m^2/person. Before 2005, lighting density was 25 W/m^2 and was reduced to 11 W/m^2 in 2005 regulation. Moreover, equipment density is 20 W/m^2. According to regulation [44], a modulating percentage was assigned in the simulation of daily human density and utilization of lighting and equipment systems. Typically, there are no human inside the building from 0:00 - 07:00 and 20:00 - 24:00. Hence, utilization of equipment will be 0%. From 8:00 - 9:00, people arrive at office and it is assumed that utilization of equipment is 50%. During the working period from 9:00 – 12:00 and 14:00 – 18:00, utilization will be 95% according to regulation. At lunch time (12:00 – 14:00), utilization will be 80%. Lastly, at closing hour (18:00 – 20:00), utilization will be 30%.

Table 3: Regulation for HVAC System [43, 50]

HVAC parameter	Value
Refrigerator COP	5.5
Energy efficiency ratio	3.2
Fan efficiency	0.7
Fresh air	8.3L/s/person
Fresh air temperature (^oC)	14
Indoor design temperature (^oC):	
- summer	22 - 28
- winter	16 - 22
Infiltration	0.2 ACH in perimeter area, 0 ACH in internal area

Table 4. Human comfort requirement

Requirement	Summer	Winter
HVAC temperature control	22 – 28 ^oC	16 - 22 ^oC
Humidity	50%	50%
Air Change Rate	1 ach^{-1}	1 ach^{-1}
Wind Sensitivity	0.5 ach^{-1}	0.5 ach^{-1}

3. Results and discussion

3.1 Data collection

Shanghai has 16 districts (Fig. 2(a)), each with a different share of non-residential building types and ranking (Table 5). In total, there are 62,231 × 10^4 m^2 of non-residential building area in Shanghai with office building blocks accounting for 8150 × 10^4 m^2. Due to the difficulty in studying this vast number of buildings, it is good practice to conduct studies on one specific district, particularly one with a high number of non-residential buildings. From Table 5, Pu Dong and Min Hang district are the first and second largest in terms of non-residential buildings with 14,013 and 6,414 m^2 building area. However, Pu Dong district was developed after the year 2000 and most buildings in this district are new and meet the design standards for energy-efficient buildings. Hence, it is reasonable to select Min Hang district (shown in Fig. 2(b)), for this research purpose with a high number of non-residential buildings and a wider variety of building years.

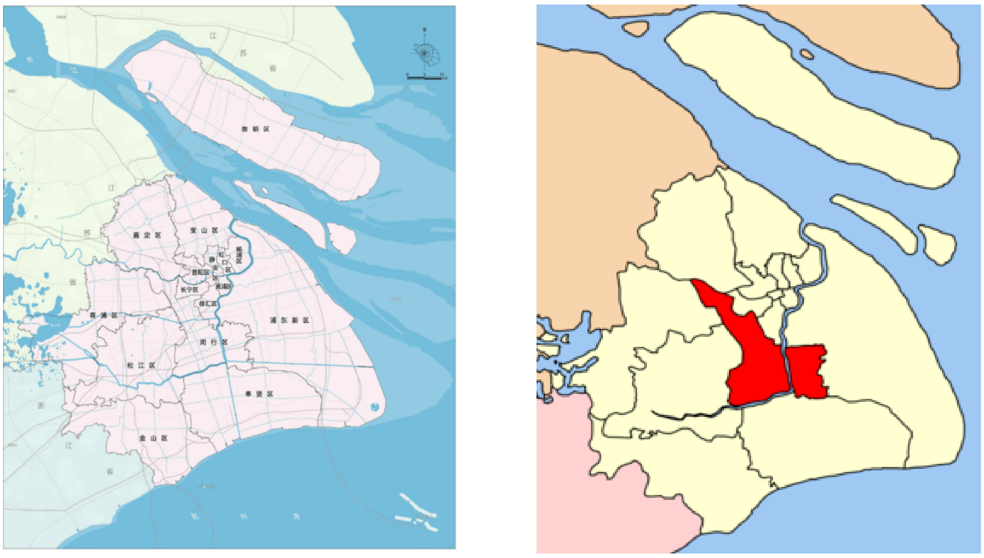


Fig. 2. Map of (a) districts in Shanghai, and (b) Min Hang District

Table 5. Summary of non-residential buildings and office buildings in Shanghai [51].

District	**Non-Residential Buildings (10^4 m^2)**	**Non-Residential Buildings Area Rank**	**Land Area (km^2)**	***Offices* Area (10^4 m^2)**	**Volume ratio (Density)**
Total	62 231		6340.50	8 150	0.09
Pu Dong New Area	14 013	1	1210.41	1 777	0.12
Huang Pu	2 035	13	20.46	758	0.99
Xu Hui	2 755	9	54.76	773	0.50
Chang Ning	1 724	14	38.30	585	0.45
Jing an	2 644	10	37.37	724	0.71
Pu Tuo	2 331	12	54.83	519	0.43
Hong Kou	1 410	15	23.48	448	0.60
Yang Pu	2 532	11	60.73	484	0.42
***Min Hang**	6 414	2	371.68	501	0.17
Bao Shan	4 227	5	270.99	290	0.16
Jia Ding	4 836	4	458.80	451	0.11
Jin Shan	3 081	8	586.05	159	0.53

Song Jiang	5 738	3	604.71	230	0.09
Qing Pu	3 780	6	675.54	164	0.06
Feng Xian	3 677	7	687.39	208	0.05
Chong Ming	1 033	16	1185.49	79	0.01

*District selected for sampling

To this regard, an on-site survey study was performed in Min Hang district to collect statistical data of existing office buildings. According to different building regulation standard released in 1980 and 2005, there are 408 and 1078 existing office buildings constructed before 2005 and between 2006-2015 respectively (see Table 6). Moreover, restricting the height of low-rise buildings to 24 meters (or 6 floors) [46], there are 1121 low-rise office buildings, which accounts for 75.4% of the total existing office buildings in Min Hang district of Shanghai.

Table 6. Existing office buildings in Min Hang district

Floors	**≤ 2005 (C1)**	**2006 - 2015 (C2)**	**Total**	**Percentage**
1-6 floors	296	825	1121	75%
≥ 7 floors	112	253	365	24%
Total	408	1078	1486	
Percentage	27%	73%		100%

Table 7. Breakdown of selected low-rise office buildings in Min Hang district

Floors	**≤ 2005 (C1)**	**2006 - 2015 (C2)**	**Total**	**Percentage**
1	-	-	**-**	**-**
2	3	-	**3**	**2%**
3	-	35	**35**	**26%**
4	4	71	**75**	**55%**
5	15	-	**15**	**11%**
6	1	7	**8**	**6%**
Total	**23**	**113**	**136**	**100%**
Percentage	**17%**	**83%**	**100%**	

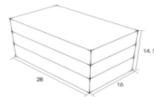
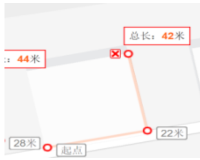
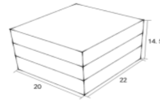
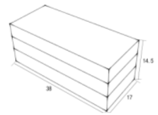
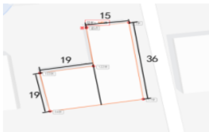
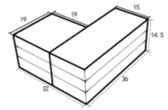
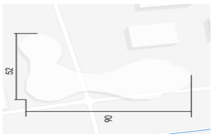
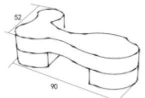
In order to sustain the ratio of buildings between C1 and C2, a total of 10 office parks containing 136 single low-rise office buildings, which accounted for about 10% of the existing low-rise office blocks in this district was surveyed in Shanghai. Table 7 shows a breakdown of the selected building samples. The locations of these parks are illustrated in Fig. 3, with their addresses, construction year, and building distribution presented in Table 8. According to the number of buildings within C1 and C2, the ratio was 23:113 ≈ 1.6:7.3, which is close to the actual ratio of 2.7:7.3 for the existing low-rise office buildings in the district. Taking Hong Xing International Square and Cao He Jing Office Park as examples of C2 and C1, Tables 9 and 10 present the specific building characteristics of the surveyed low-rise office buildings built within 2006 – 2015, and before 2005, respectively.

Fig. 3. Location of the selected office parks in Min Hang district

Table 8. The selected office parks in Min Hang District

No.	**Name**	**Location**	**Construction Year**	**No. of Buildings (No. of floors)**
1	Hong Xing International Square	No. 1969 Puxing Rd.	2014	32 (3 floors)
2	Pu Jiang Yi You Office Park	No. 1111 Hengnan Rd.	2014	18 (4 floors)
3	CIFI Pu Jiang International Square	No. 1650 Lianhang Rd.	2013	30 (4 floors)
4	Pu Jiang Science and Technology Park	No. 2388 Chenhang Rd.	2011	2 (3 floors), 2 (4 floors)
5	Cao He Jing Park	No. 2388 Chenhang Rd.	2004	13 (5 floors)
6	Vanke Zao City	No. 588 Beijiangju Rd.	2013	7 (6 floors)
7	Vanke VMO Park	No. 2049 Pujin Rd.	2011	1 (3 floors), 21 (4 floors)
8	Fawkes Chain Business Building (HongMei South Rd)	Hongmei South Rd, Meilong Town	2004	1 (6 floors), 1 (2 floors)
9	Fawkes Chain Business Building (Hu Guang East Rd)	No. 89 Huguang East Rd	2004	3 (2 floors), 1 (5 floors)
10	Fawkes Chain Business Building (Dou Zhuang Rd)	No.2755 Yindu Rd.	2005	4 (4 floors)

Table 9. Specific building characteristics of selected low-rise buildings built within 2006-2015 (All dimensions are in metric units).

Office park name	Hong Xing International Square								
Building number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
1.3.5.6.7.8.9.10.12.14.15.16.18.19.20.21.22.23		28	16	14.5	3	1344			18
2.4		22	20	14.5	3	1320			2
24.25.26.27.28.29.30.31		38	17	14.5	3	1938			8
13.17		36	32	14.5	3	2748			2
11		90	52	14.5	3	2575			1

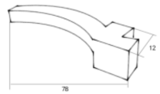
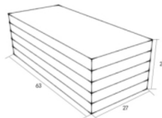
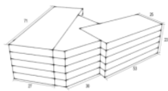
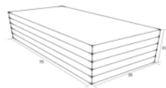
32		78	12	14.5	2	1550			1

Table 10. Specific characteristics of selected low-rise buildings built before 2005 (all dimensions are in metric units).

Office park name	Cao He Jing Office Park								
Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
2.3.4.5.6.7.8.9.10. 11.12		63	27	23	5	8550			11
1		71	27	23	5	21225			1
13		75	35	23	5	13125			1

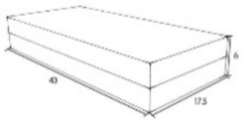
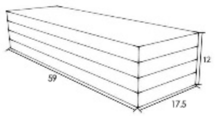
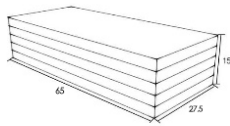
3.2. Building prototypes for low-rise office buildings in Shanghai and their associated energy consumption

Based on the aforementioned PIS, the surveyed buildings were classified using on-site survey data. For instance, according to the construction year, the buildings were divided into two categories C1 (≤ 2005) and C2 (2006 - 2015). Each period is characterized by a typical construction practice of the building envelope, particularly the employed materials and their thermophysical properties. Moreover, according to the building plan forms, existing low-rise office buildings before 2005 had a rectangle plan form; while buildings between 2006 - 2015 had both rectangle and square shape. Furthermore, classifications involving a minor number of buildings were ignored while developing the prototypes. Based on the number of buildings, seven typical classifications were identified. The typical classification included three buildings (B1, B2 and B3) from the construction year (C1), and four buildings (B1, B2, B3 and B4) from the construction year (C2).

- For C1:
  - C1B1: R plan form with 700 m^2 floor area, < 0.2 W/W ratio and 2 floors,
  - C1B2: R plan form with 1032.5 m^2 floor area, 0.2 - 0.4 W/W ratio and 4 floors,
  - C1B3: R plan form with 1787.5 m^2 floor area, 0.2 - 0.4 W/W ratio and 5 floors.
- For C2:
  - C2B1: R plan form with 555 m^2 floor area, 0.2 - 0.4 W/W ratio and 3 floors,
  - C2B2: R plan form with 408 m^2 floor area, > 0.4 W/W ratio and 4 floors,
  - C2B3: R plan form with 1809 m^2 floor area, > 0.4 W/W ratio and 6 floors,
  - C2B4: S plan form with 306 m^2 floor area, > 0.4 W/W ratio and 3 floors.

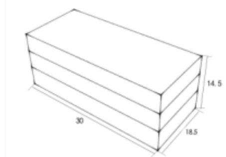
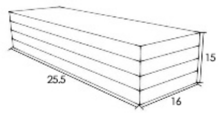
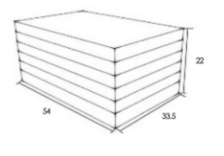
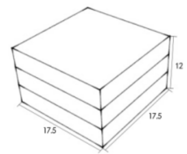
Further details of the typical buildings' characteristics are presented in Tables 11 and 12 for buildings under C1 and C2, respectively. Using IES-VE simulation software and metered data, the energy consumption and EUI for each building prototypes were obtained. In this study, EUI is defined as the ratio of building energy consumption to the building area. Simulation validation was conducted by comparing simulated energy results for prototypes C1B1 and C2B1 with actual metered data from the representative buildings. Simulated results were observed to be above 95% similar to actual data and demonstrate that the simulation tool is reliable for this study (Table 13).

Table 11. Low-rise office building prototypes before 2005 (C1)

PIS	**Rectangle plan form**		
	C1B1	**C1B2**	**C1B3**
No. of floors	2	4	5
Floor area* (m²)	700	1032.5	1787.5
Building area (m²)	1000-3000	3000-10000	3000-10000
Length (m)	40 (25-55)	59 (40-78)	65 (55-75)
Width (m)	17.5 (15-20)	17.5 (17-18)	27.5 (20-35)
Height (m)	6	12	15
Window/wall ratio	0.15	0.31	0.25
Sketch Model			
Representative buildings			
Yearly Energy Consumption	176.5 MWh/year	587.6 MWh/year	1181.6 MWh/year
Energy Use Intensity	126.06 kWh/m²	142.26 kWh/m²	132.20 kWh/m²

* the values are exact estimates obtained from the on-site survey of the selected building samples

Table 12. Low-rise office building prototypes between 2006 - 2015 (C2)

PIS	Rectangle plan form			Square plan form
	C2B1	**C2B2**	**C2B3**	**C2B4**
No. of floors	3	4	6	3
Floor area* (m^2)	555	408	1809	306
Building area (m^2)	1000-3000	1000-3000	>10000	1000-3000
Length (m)	30 (22-38)	25.5 (21-30)	54 (45-63)	17.5 (15-20)
Width (m)	18.5 (15-22)	16 (12-20)	33.5 (33-34)	17.5 (15-20)
Height (m)	14.5	15	22	12
Window/wall ratio	0.13	0.46	0.44	0.61
Sketch Model				
Representative buildings				
Yearly Energy Consumption	164.0 MWh/year	201.6 MWh/year	1266.8 MWh/year	132.4 MWh/year
Energy Use Intensity	98.50 kWh/m^2	123.53 kWh/m^2	116.71 kWh/m^2	144.23 kWh/m^2

* the values are exact estimates obtained from the on-site survey of the selected building samples

Table 13. Comparison of actual with simulated energy consumption for prototypes C2B1 and C1B1

Building	Prototype	Building floor	Actual energy consumed (kWh/yr)	Simulated energy consumed (MWh/yr)
Building 60 in Hong Xing Int'l Square	C2B1	2 and 3	113,921.30	
		1	42,309.74	
		Total	156,231.04	164.0 (95%)
Building 1 Fawkes Chain Business Building (Chun Shen Road)	C1B1	2	89,626.07	
		1	80,382.26	
		Total	170,008.33	176.5 (96%)

Using the proposed typical buildings, the simulated EUI is presented in Tables 11 and 12 for buildings under C1 and C2, respectively. The energy consumption for the typical buildings under C1, C1B1, C1B2 and C1B3, are 176.5 MWh, 587.6 MWh and 1181.6 MWh, respectively. Concerning C2, 164.0 MWh, 201.6 MWh, 1266.8 MWh and 132.4 MWh were estimated energy consumptions for C2B1, C2B2, C2B3 and C2B4, respectively. As a result, the building EUI within C1 varied from 126.06 - 142.26 kWh/m^2 with an average of 133.51 kWh/m^2, whereas for C2, the building EUI varied from 98.50 – 144.23 kWh/m^2 with an estimated average of 120.74 kWh/m^2. As expected, the building energy consumption after 2005 showed a significant decline when compared to that before 2005. The decline can be attributed to the upgrade in building envelope material with improved thermophysical properties.

3.3 Correlation between building performance index and energy consumption

Among the indexes mentioned above, the most influential on building EUI was investigated using correlation analysis of the data from the 136 office building samples. Table 14 presents the correlation analysis of the other building performance indexes (excluding building area) with respect to the building EUI. The most influential indexes from the analysis are then chosen for further building classifications. Pearson correlation coefficient served as the critical indicator for reflecting the degree of linear correlation between the indexes and the annual building EUI. However, for the dichotomous variables, a ranked Biserial correlation coefficient was used instead. Excel statistical tool, XLSTAT (version 2019.3.2) software was used for the computation of the correlation coefficients. Pearson and Biserial correlation coefficients are calculated using equations (1) and (2), respectively:

$$r = \frac{Cov(x,y)}{\sqrt{Var(x).Var(y)}} \tag{1}$$

$$r = \frac{(\overline{y_1} - \overline{y_2})\sqrt{P_1.P_2}}{S_y} \tag{2}$$

where Cov(x,y) is the covariance of x and y variables, Var(x) is the variance of x variable (classification index), and Var(y) is the variance of y variable (EUI), $\overline{y_1}$ and $\overline{y_2}$

are the mean values of y variables of the dichotomous groups 1 and 2, respectively; P_1 and P_2 are the proportion of groups 1 and 2, respectively; and S_y is the standard deviation of the population.

A confirmatory data analysis using two-tailed significance was computed using the f-test statistics:

$$f = \frac{\dfrac{\sum_{i=1}^{k} n_i(\overline{x_i} - \overline{X})^2}{(k-1)}}{\dfrac{\sum_{i=1}^{k}\sum_{j=1}^{n_i}(x_{ij} - \overline{x_i})^2}{(N-k)}} \tag{3}$$

where n_i is the number of observations in the i^{th} sample group, $\overline{X}$ is the overall sample mean value of the data, k is the number of groups, x_{ij} is the j^{th} observation in the i^{th} sample group out of the k number of groups and N is the overall sample size. $\overline{x_i}$ is the mean value in the i^{th} sample group, and is defined as:

$$\overline{x_i} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{4}$$

where x_i is the observed value of the i^{th} sample group, and n is the number of observations in the sample. Regarding this study, this data analysis includes a total of seven sample groups, each with six observations. The sample groups and observations represent the seven typical classes of building and the classification indexes, respectively.

Table 14. Correlation analysis of annual average building energy consumption per unit floor area of each index

Classification Index	**Average annual energy consumption per unit area**	
	Pearson correlation	**f-value (2-tailed sig.)**
Plan form	0.3684	0.2868
Number of floors	0.3075	0.5022
Heat/cold source	0.1773	0.7038
Construction year	0.6056	0.1149
Window/wall ratio	0.2006	0.6662
Building orientation	0.3684	0.2904

From Table 14, it is evident that the correlation coefficient reflects the following trend: construction year > plan form > building orientation > number of floors > window/wall ratio > heat or cold source type. The f-value of the significance test validates the trend. The f-value compares the joint effect of all the indexes together. A larger f-value denotes a more significant index. This result indicates that the building form and orientation, number of floors and W/W ratio are the major influencing factors with high significance for building energy consumption per unit area.

Furthermore, cluster analysis was adopted to characterize the indexes further. Clustering method of simplest and shortest distance was selected in this study while using Z-score for standardizing conversion values. The detailed steps of the cluster analysis are defined in reference [42] as follows:

Step 1. Calculate the distance between the samples using the squared Euclidean distance. This will aid generate the symmetric matrix shown in Table 15.

Step 2. The smallest non-zero element in the symmetric matrix was selected, and the two samples with the minimum distance denoted as D_{m1}. The two samples are then merged into one class, C_{m1}.

Step 3. Calculate the distance between C_{m1} and other samples; repeat the above steps until all samples are combined into one class, as shown in Table 16.

Table 15. Symmetric matrix of Euclidean distances

Index*	1	2	3	4	5	6
1	0	0.0128	0.0011	0.0030	6.4843	0.0032
2	0.0128	0	0.0120	0.0101	6.4723	0.0104
3	0.0011	0.0120	0	0.0022	6.4836	0.0023
4	0.0030	0.0101	0.0022	0	6.4815	0.0012
5	6.4843	6.4723	6.4836	6.4815	0	6.4820
6	0.0032	0.0104	0.0023	0.0012	6.4820	0

*1: Plan form, 2: Number of floors, 3: Window/wall ratio, 4: Heat and cold source type, 5: Construction year, 6: Building orientation.

The variable cluster analysis in Fig. 4 and Table 16 shows a 3-class and 4-class clustering of the indexes influencing the building EUI. The 4-class clustering indicates that plan form and window/wall (W/W) ratio formed the first cluster; heat and cold source type and building orientation formed the second cluster; while the number of floors and construction year individually formed the other two clusters. Under the 3-class clustering, plan form and window/wall ratio, heat and cold source type and building orientation are grouped under the first cluster; while the number of floors and construction year made up the second and third clusters, respectively.

The clustering analysis stipulates that construction year, number of floors, window-wall ratio and building orientation are the fundamental influencing factors, as depicted by the 4-class clustering. This finding corresponds with the correlation analysis presented earlier. In addition, it also matches with reported research findings from a similar city with the same climatic condition [42]. However, most buildings in this city are positioned in the N-S orientation, which makes the classification of buildings about this index (building orientation) to be less thorough. Therefore, it is logical to stipulate that the construction year, number of floors and window-wall ratio are the leading indexes for low-rise office building classification (as depicted by the 3-class clustering).

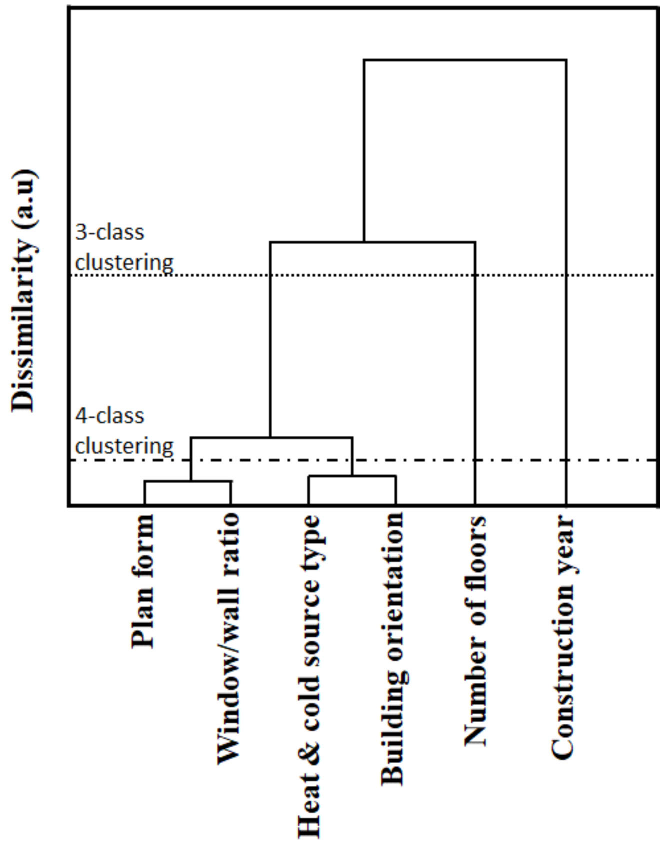


Fig. 4. Cluster analysis tree of office building indexes in Min Hang district, Shanghai

Table 16. Variable cluster analysis result for office building indexes in Min Hang district, Shanghai

Classification index	3-class clustering	4-class clustering
Plane form	1	1
Number of floors	2	3
Heat/cold source	1	2
Construction year	1	4
Window/wall ratio	3	1
Building orientation	1	2

3.4 Standard building assortment

Based on the statistical analysis, the 136 surveyed buildings were afterwards analyzed according to their construction year, number of floors, and W/W ratio, as shown in Table 17. The W/W ratio was classified into three: < 0.2 (W1), 0.2 – 0.4 (W2), and > 0.4 (W3). Table 17 illustrates that the number of floors for most buildings before 2005 ranged between 4 and 5 floors, which accounted for a total of *approx.* 83% of the surveyed buildings. About W/W ratio, most buildings before 2005 were categorized under W2, which accounted for *approx.* 87% of the surveyed buildings. In general, the analysis demonstrates that buildings with 4 and 5 floors and with W/W ratio of 02 – 0.4 were more prominent for low-rise offices building typologies within this period.

Between 2006-2015 (C2), most low-rise office buildings have 3 and 4 number of floors, which accounted for *approx.* 31% and 63% respectively of the surveyed buildings. Also, the W1 and W3 ratios were the more prominent W/W ratio within this construction year with a building share of *approx.* 27% and 72%, respectively. Overall, the statistical analysis within this period shows that most low-rise office buildings displayed a low or high W/W ratio with 3 and 4 number of floors.

Using the probability theory, an occurrence probability greater than 5% is considered as a significant probability of event [42]. Hence, an occurrence value above six buildings in Table 17 is the threshold for a significant-probability event in order to identify the prototypical buildings. Table 18 presents the breakdown of the prototypical buildings using significant probability theory. From Table 18, the most typical building prototypes are classified into four classes:

W1F3 = buildings with W/W ratio < 0.2 and 3 floors;
W2F5 = buildings with W/W ratio from 0.2 – 0.4 and 5 floors;
W3F4 = buildings with W/W ratio > 0.4 and with 4 floors; and
W3F6 = buildings with W/W ratio > 0.4 and with 6 floor

Adopting the probability theory, W2F5 was the only building prototype identified in the construction year C1, with an estimated 65% building share. However, for the C2 construction year, W1F3, W3F4 and W3F6 were the identified prototypical buildings with building shares of *approx.* 27%, 63% and 6%, respectively. Overall, the four prototypical buildings, W1F3, W2F5, W3F4 and W3F6 exhibited building shares of *approx.* 23%, 11%, 53% and 5%, respectively of the total surveyed buildings.

In summary, C1W2F5, C2W1F3, C2W3F4 and C2W3F6 are the four main prototypical buildings identified within Min Hang district of Shanghai. Lastly, a typical building representing each of this prototype is selected as the standard building, which will be adopted for subsequent studies and the development of adequate retrofit measures. The typical buildings representing each prototype is shown in Tables 19 - 22.

Table 17. Statistics of the building samples with regards to construction year, number of floors and W/W ratio.

No. of floors	Window-wall (W/W) ratio						Total
	< 2005			2006 - 2015			
	< 0.2	0.2 – 0.4	> 0.4	< 0.2	0.2 – 0.4	> 0.4	
2	2	1	-	-	-	-	**3**
3	-	-	-	31	1	3	**35**
4	-	4	-	-	-	71	**75**
5	-	15	-	-	-	-	**15**
6	-	-	1	-	-	7	**8**
Total	**2**	**20**	**1**	**31**	**1**	**81**	**136**

Table 18. Breakdown of prototypical buildings with regards to the number of floors and W/W ratio for different construction year.

Construction year	Prototypical buildings*				Others	Total
	W1F3	W2F5	W3F4	W3F6		
< 2005	-	15 (65.22%)	-	-	8 (34.78%)	**23 (100.00%)**
2006 - 2015	31 (27.43%)	-	71 (62.83%)	7 (6.20%)	4 (3.54%)	**113 (100.00%)**
Total	**31 (22.79%)**	**15 (11.03%)**	**71 (52.51%)**	**7 (5.15%)**	**12 (8.82%)**	**136 (100.00%)**

*W1F3 = buildings with W/W ratio < 0.2 and 3 floors; W2F5 = buildings with W/W ratio from 0.2 – 0.4 and 5 floors; W3F4 = buildings with W/W ratio > 0.4 and with 4 floors; and W3F6 = buildings with W/W ratio > 0.4 and with 6 floors.

Table 19. The typical building of C1W2F5: No. 2388 Chenhang Road.

Construction year	2004	**Window/wall ratio**	0.25
Plan form	Rectangular with 2.33 L/W ratio	**Heat and cold source type**	Dispersion
Structure type	Brick/frame structure	**Floor area**	1787.5 m^2
Height	15 m	**EUI**	132.20 kWh/m^2

Table 20. The typical building of C2W1F3: No. 1969 Puxing Rd.

Construction year	2014	**Window/wall ratio**	0.13
Plan form	Rectangular with 1.62 L/W ratio	**Heat and cold source type**	Dispersion
Structure type	Concrete structure	**Floor area**	555 m^2
Height	14.5 m	**EUI**	98.50 kWh/m^2

Table 21. The typical building of C2W3F4: No. 1650 Lianhang Road.

Construction year	2013	**Window/wall ratio**	0.46
Plan form	Rectangular with 1.11 L/W ratio	**Heat and cold source type**	Dispersion
Structure type	Concrete structure	**Floor area**	408 m^2
Height	15 m	**EUI**	123.53 kWh/m^2

Table 22. The typical building of C2W3F6: No. 588 Beijiangju Rd.

Construction year	2013	**Window/wall ratio**	0.44
Plan form	Rectangular with 1.61 L/W ratio	**Heat and cold source type**	Dispersion
Structure type	Concrete structure	**Floor area**	1809 m^2
Height	22 m	**EUI**	116.71 kWh/m^2

5. Conclusion and future research directions

To identify an efficient building retrofitting strategy for low-rise office buildings, it is crucial to establish prototypical buildings as representative standards for large building stocks. Here, a methodical approach is proposed to single out prototypes using core architectural indexes obtained from an on-site survey of 136 low-rise office buildings from a central urban area in Shanghai city. The proposed indexes include construction year, window/wall ratio, number of floors, plan form, building orientation, and the types of cold and heat sources. Based on collated data, the following conclusions were deduced:

1. Seven typical buildings are obtained after a detailed statistical analysis and classification using the proposed performance indexes. The typical buildings include six rectangle buildings and one single square building: three rectangular buildings built before 2005; three rectangle buildings built between 2006-2015; and one square building built between 2006-2015.

2. Using correlation analysis, the building plan form and orientation, number of floors and W/W ratio are the major influencing factors with high data significance for building energy consumption per unit area.

3. With agglomerate cluster analysis, the construction year, number of floors, window-wall ratio and building orientation are the fundamental cluster centroids. This analysis provides building indexes that should be used to determine prototypical buildings and can be applied for the study of existing buildings needing retrofitting.

4. Based on the most influencing indexes, four prototypical buildings were established: C2W1F3 (buildings with W/W ratio < 0.2 and 3 floors), C2W3F4 (buildings with W/W ratio > 0.4 and with 4 floors), and C2W3F6 (buildings with W/W ratio > 0.4 and with 6 floor), built between 2006-2015, and C1W2F5 (buildings with W/W ratio from 0.2 – 0.4 and 5 floors) built before 2005.

This research is part of a Phd project that aims to provide an integrated framework for green retrofitting package (GRP) for low-rise office buildings in Shanghai. It proposes a methodological approach for building classification, evaluation of energy performance based on building characteristics and identification of key performance index for building stocks that require energy conservative measures. This research has laid down a foundation that will guide the *ex-post* and *ex-ante* assessment of retrofit measures. Based on this, a decision-making toolkit can be further developed that can help urban managers and investors to identify the optimum retrofitting strategies.

Limitation and future development

In this study, a thorough assessment of the HVAC system, ventilation mechanism and varying working hour schedule was not conducted due to the limited preferences in China's building standards. Also, the building management and control index was not considered in the building prototype identification. These indexes were assumed on a general perspective across all building samples. In order to improve the efficacy of the methodology, further analysis incorporating specific details of these indexes is suggested.

Besides, the classification methodology developed in this study is not restricted to the 136 building samples in Min Hang district in Shanghai only but can be extended to a variety of building classification cases and also, the other districts and cities. It is worth mentioning that data from more buildings and other districts would add more robustness to the study. Also, this approach does not alleviate the process of data acquisition on building characteristics but rather provides a significant comparison platform for similar buildings.

In this study, we mainly focused on low-rise office buildings in Min Hang district of Shanghai. These buildings account for more than 75% of office buildings built before 2015. In order to achieve the set building standards beyond 2015, this work serves as a preliminary step for the establishment of representative building standards that will guide the design of optimal building retrofitting strategy for low-rise office buildings in Shanghai.

Furthermore, as most cities in China expand at a fast rate, new low-rise buildings built after 2016 will also reflect valuable information of newly developed urban zones, and thus are worth studying for energy retrofit strategies. This study will also aid in a better comparison and update of building prototypes in Shanghai.

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References

1. Ren, J., et al., *Influencing factors and energy-saving control strategies for indoor fine particles in commercial office buildings in six Chinese cities.* Energy and Buildings, 2017. **149**: p. 171-179.
2. Chen, H. and W.L. Lee, *Energy assessment of office buildings in China using LEED 2.2 and BEAM Plus 1.1.* Energy and Buildings, 2013. **63**: p. 129-137.
3. Lin, B., et al., *Investigation of winter indoor thermal environment and heating demand of urban residential buildings in China's hot summer – Cold winter climate region.* Building and Environment, 2016. **101**: p. 9-18.
4. Hong, Y., W. Deng, and C.I. Ezeh, *Low-rise Office Retrofit: Prerequisite for Sustainable and Green Buildings in Shanghai.* IOP Conference Series: Earth and Environmental Science, 2019. **281**: p. 012025.
5. Wang, Z., et al., *Residential heating energy consumption modeling through a bottom-up approach for China's Hot Summer–Cold Winter climatic region.* Energy and Buildings, 2015. **109**: p. 65-74.
6. Ichinose, T., L. Lei, and Y. Lin, *Impacts of shading effect from nearby buildings on heating and cooling energy consumption in hot summer and cold winter zone of China.* Energy and Buildings, 2017. **136**: p. 199-210.
7. Wang, Z., et al., *Rational selection of heating temperature set points for China's hot summer – Cold winter climatic region.* Building and Environment, 2015. **93**: p. 63-70.
8. Liu, X., G.J.D. Hewings, and S. Wang, *Evaluation on the impacts of the implementation of civil building energy efficiency standards on Chinese economic system and environment.* Energy and Buildings, 2009. **41**(10): p. 1084-1090.

9. Yin, R., P. Xu, and P. Shen, *Case study: Energy savings from solar window film in two commercial buildings in Shanghai.* Energy and Buildings, 2012. **45**: p. 132-140.
10. Carlson, K. and D.K.D. Pressnail, *Value impacts of energy efficiency retrofits on commercial office buildings in Toronto, Canada.* Energy and Buildings, 2018. **162**: p. 154-162.
11. Kontokosta, C.E., *Modeling the energy retrofit decision in commercial office buildings.* Energy and Buildings, 2016. **131**: p. 1-20.
12. Zheng, L. and J. Lai, *Environmental and economic evaluations of building energy retrofits: Case study of a commercial building.* Building and Environment, 2018. **145**: p. 14-23.
13. Eliopoulou, E. and E. Mantziou, *Architectural Energy Retrofit (AER): An alternative building's deep energy retrofit strategy.* Energy and Buildings, 2017. **150**: p. 239-252.
14. Xin, L., et al., *Effect of the energy-saving retrofit on the existing residential buildings in the typical city in northern China.* Energy and Buildings, 2018. **177**: p. 154-172.
15. Asdrubali, F., et al., *Energy and environmental payback times for an NZEB retrofit.* Building and Environment, 2019. **147**: p. 461-472.
16. Mora, D., et al., *Occupancy patterns obtained by heuristic approaches: Cluster analysis and logical flowcharts. A case study in a university office.* Energy and Buildings. **186**: p. 147-168.
17. Buttitta, G., W. Turner, and D. Finn, *Clustering of Household Occupancy Profiles for Archetype Building Models.* Energy Procedia. **111**: p. 161-170.
18. Diao, L., et al., *Modeling energy consumption in residential buildings: A bottom-up analysis based on occupant behavior pattern clustering and stochastic simulation.* Energy and Buildings. **147**: p. 47-66.
19. Ma, Z., R. Yan, and N. Nord, *A variation focused cluster analysis strategy to identify typical daily heating load profiles of higher education buildings.* Energy. **134**: p. 90-102.
20. Gaitani, N., et al., *Using principal component and cluster analysis in the heating evaluation of the school building sector.* Applied Energy. **87**(6): p. 2079-2086.
21. FilippÃ n, C., F. Ricard, and S. Flores Larsen, *Evaluation of heating energy consumption patterns in the residential building sector using stepwise selection and multivariate analysis.* Energy and Buildings. **66**: p. 571-581.
22. Wu, Y., et al., *Fast and Simple Preparation of Iron-Based Thin Films as Highly Efficient Water-Oxidation Catalysts in Neutral Aqueous Solution.* Angewandte Chemie International Edition, 2015. **54**(16): p. 4870-4875.
23. Deb, C. and S.E. Lee, *Determining key variables influencing energy consumption in office buildings through cluster analysis of pre- and post-retrofit building data.* Energy and Buildings. **159**: p. 228-245.
24. Gao, X. and A. Malkawi, *A new methodology for building energy performance benchmarking: An approach based on intelligent clustering algorithm.* Energy and Buildings. **84**: p. 607-616.
25. Gui, X.-c., et al., *The methodology of standard building selection for residential buildings in hot summer and cold winter zone of China based on architectural typology.* Journal of Building Engineering. **18**: p. 352-359.

26. Ye, Y., et al., *A methodology to create prototypical building energy models for existing buildings: A case study on U.S. religious worship buildings.* Energy and Buildings, 2019. **194**: p. 351-365.
27. Singh, S.P. and V. Bhat, *Performance evaluation of dual phase change material gypsum board for the reduction of temperature swings in a building prototype in composite climate.* Energy and Buildings, 2018. **159**: p. 191-200.
28. Briggs, R.S., D.B. Crawley, and J.S. Schliesing, *Energy requirements for office buildings. Volume 1, Existing buildings. GRI-90/0236.1 by Battelle, Pacific Northwest Laboratory, for Gas Research Institute.* 1992.
29. Ma, Z., et al., *Existing building retrofits: Methodology and state-of-the-art.* Energy and Buildings, 2012. **55**: p. 889-902.
30. Santamourisa, M., et al., *Energy conservation and retrofitting potential in Hellenic hotels.* Energy & Buildings, 1996. **24**(1): p. 65-75.
31. (TABULA), T.A.f.B.S.E.A., *TABULA building typologies - country pages*. 2016, Institut Wohnen und Umwelt GmbH http://episcope.eu/building-typology/country/ (Last accessed on 10th November, 2019): Institut Wohnen und Umwelt GmbH.
32. Monteiro, C.S., et al., *The Use of Multi-detail Building Archetypes in Urban Energy Modelling.* Energy Procedia, 2017. **111**: p. 817-825.
33. Ballarini, I., S.P. Corgnati, and V. Corrado, *Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project.* Energy Policy, 2014. **68**: p. 273-284.
34. Li, X., et al., *Developing urban residential reference buildings using clustering analysis of satellite images.* Energy and Buildings, 2018. **169**: p. 417-429.
35. Shahrestani, M., R. Yao, and G.K. Cook, *A review of existing building benchmarks and the development of a set of reference office buildings for England and Wales.* Intelligent Buildings International, 2014. **6**(1): p. 41-64.
36. Hernandez, P., K. Burke, and J.O. Lewis, *Development of energy performance benchmarks and building energy ratings for non-domestic buildings: An example for Irish primary schools.* Energy and buildings, 2008. **40**(3): p. 249-254.
37. Stocki, M., D.C. Curcija, and M.S. Bhandari, *The Development of Standardized Whole-Building Simulation Assumptions for Energy Analysis for a Set of Commercial Buildings.* ASHRAE Transactions, 2007. **113**(2).
38. Torcelini, P., et al., *DOE Commercial Building Benchmark Models. Proceeding in conference: 2008 ACEEE Summer Study on Energy Efficiency in Buildngs, Pacific Grove, California, Volume-pp: 4-305; 4-316*. 2008.
39. Ali, U., et al., *A data-driven approach for multi-scale building archetypes development.* Energy and Buildings, 2019. **202**: p. 109364.
40. Kragh, J. and K.B. Wittchen, *Development of two Danish building typologies for residential buildings.* Energy & Buildings, 2014. **68**(68): p. 79-86.
41. Ballarini, I., S.P. Corgnati, and V. Corrado, *Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project.* Energy Policy, 2014. **68**(68): p. 273-284.

42. Gui, X.-c., et al., *The methodology of standard building selection for residential buildings in hot summer and cold winter zone of China based on architectural typology.* Journal of Building Engineering, 2018. **18**: p. 352-359.
43. MOHURD, *Public Building Energy Saving Design Standard, GB-50189.* China National Code, 2005.
44. MOHURD, *Design standard for energy efficiency of public buildings GB50189-2015*, Ministry of Housing and Urban-Rural Development of the China, Editor. 2015: China.
45. Ministry of Housing and Urban-Rural Deveiopment of China, *China Design Code for Office Building JCJ67-2006.* 2006.
46. China Construction Department, *Standard for energy consumption survey of civil buildings JCJ/T 154-2007*, China Construction Department, Editor. 2007: China.
47. Peri, G., et al., *Environmentally Assessing Buildings Characterized by Complex Shape and Innovative Materials.* Advanced Materials Research, 2013. **664**: p. 409-414.
48. Wan, K.S.Y. and F.W.H. Yik, *Building design and energy end-use characteristics of high-rise residential buildings in Hong Kong.* Applied Energy, 2004. **78**(1): p. 19-36.
49. Ornstein, M., *A Companion to Survey Research*, K. Metzler, Editor. 2013, SAGE Publications Ltd: London DOI: 10.4135/9781473913943.
50. MOHURD, *The minimum allowable values of the energy efficiency and energy efficiency grades for unitary air conditioners, GB-19576-2004*, M.o.H.a.U.R. Development, Editor. 2005: China.
51. Bureau, S.M.S., *Shanghai Statistical Yearbook 1980-2017*, S.M.S. Bureau, Editor. 2017: Shanghai.

Correlation between building characteristics and associated energy consumption: Prototyping low-rise office buildings in Shanghai

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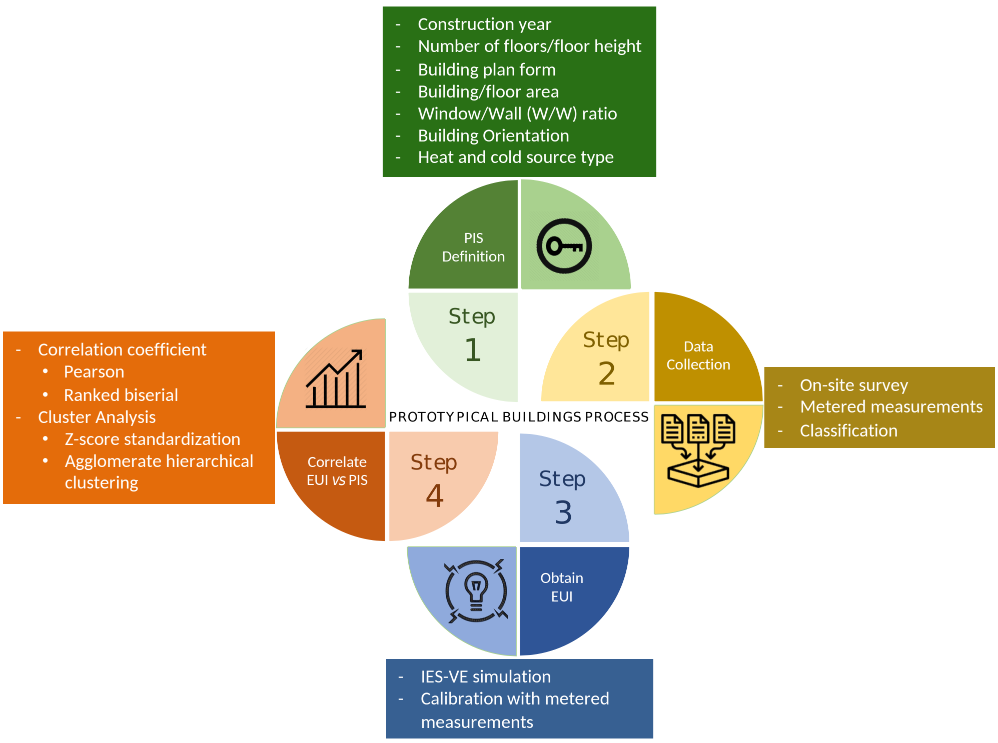
Graphical Abstract



Correlation between building characteristics and associated energy consumption: Prototyping low-rise office buildings in Shanghai

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Abstract

The enormous building energy consumption in Shanghai necessitates the identification of standard buildings to offer guidance for the adequate design of retrofitting strategies in order to promote a sustainable built and architectural environment. In this regard, this study develops a methodological approach to establish prototypical buildings using performance index system (PIS) founded on an on-site survey. Emphasis is focused on low-rise office buildings in Shanghai. A total of 10 office parks containing 136 single low-rise office buildings in Min Hang District were systemically selected for survey and data collection. The proposed PIS includes building orientation, number of floors, window/wall ratio, heat and cold source type, plan form, and construction year. Using cluster and correlation analysis, the surveyed buildings are classified based on the impact of each PIS on the annual building energy use intensity. Based on this approach, the most influencing indexes are construction year, the number of floors, window-wall ratio and building orientation. This result refines the surveyed building samples to four prototypical buildings as representative standards for low-rise office buildings. Subsequently, typical buildings representing each of the prototypical buildings were defined. The stipulated approach provides a systematic framework for building classification, characteristic-based evaluation of building energy performance and identification of key performance index for building retrofit purposes.

Keyword: *Low-rise, Office building, prototypes, PIS, Shanghai.*

1. Introduction

Shanghai is the largest industrial and populous city in the hot summer and cold winter (HSCW) climate zone of China. Extending 120 km from south to north, and 100 km from east to west, Shanghai has an urban population density of 6000/km^2 as at 2017 [1-4]. The broad climate variance scope of this city requires buildings to meet with anti-overheating, ventilation, and cooling requirements in summer, while anti-cold and heating requirements are also expected in winter. Consequently, this has resulted in the high building energy consumption within this city [3, 5-7]. Moreover, with the estimated rate of economic growth, building energy consumption is envisaged to grow exponentially [8, 9]. Commercial buildings, particularly office buildings, are considered as the most energy-consuming due to the intensity of activities carried out within the buildings [10-12]. Therefore, promoting sustainable office buildings in this city is required.

To promote a sustainable architectural and built environment, it is necessary to develop energy conservative measures (ECMs) for the different building typologies. Prior to the development of these measures, analytical studies on existing building stocks with an emphasis on the effect of building characteristics on the energy consumption need to be conducted. Prominent approach to determine this effect includes simulated building analysis [12-15]. For simulation purposes and further studies, it is imperative to develop prototypes that suitably represents existing building stocks and its characteristics.

However, developing prototypical buildings depends on the available data and statistics of existing building stocks, which also determines the approach to be adopted. In the circumstances with unavailable and scarce information, cluster analysis approach is considered for its inherent merits. This approach involves the grouping of variables so that the variables in a group are similar (in some sense) to each other than those in other groups. Clustering approach is widely used in the building energy analysis, such as determining characteristic occupancy patterns [16-18], load profiles [19-21], core building energy factors [22, 23], energy performance benchmarking [24] and prototypical buildings [25]. The latter uses agglomerate hierarchical clustering (AHC) of building performance index to define typical buildings able to represent the surveyed residential building stocks within Hangzhou city in Zhejiang Province of China. Nonetheless, China still lacks region-oriented information of prototypical building for building energy research studies, particularly for commercial building typology.

1.1 Review of prototypical studies on commercial building typology

Building prototypes are devised to model existing buildings and their attributes by means of a system of performance indexes. The prototypical buildings serve as an initial platform for evaluating building design, ECMs, and other analytical studies, such as energy market evaluation and policy-making [26, 27]. The performance index systems (PIS) required to determine building prototypes include building typology and their corresponding data that describes the building characteristics [28, 29]. Necessary data for this purpose were acquired from a site survey (small or large-scale survey) of existing buildings within a particular region.

A building’s shape and HVAC characteristics, as well as other factors influencing energy consumption, such as internal ambiance, building facilities, occupancy pattern and requirements, and geometric orientation, are relevant in describing a suitable prototypical building. However, the use of all these indexes to establish a prototypical building requires rigorous and complex analysis. Hence, for simplification, construction period, building type and size, and HVAC systems characteristics are the most commonly used indexes [26, 30]. The other indexes are mostly applied in the design and evaluation of building retrofit measures, which takes part after the establishment of the building prototypes [31].

Monteiro *et al.* [32] used the construction year and building shape characteristics as indexes for the identification of archetypical buildings. These indexes are the base criteria established in the TABULA (Typology Approach for Building Stock Energy Assessment) project for defining building prototypes [31]. The TABULA project suggests that building classification should be founded on the climatic area, building age class and building size class [33]. Moreover, the heat supply system should also be considered for adequate assessment of the building energy performance, particularly for *ex-post* and *ex-ante* evaluation of retrofit measures [31]. Ye *et al.* [26] adopted the weather features, building geometry, envelope, HVAC system type, schedule and internal load to create prototypes for religious buildings. Li et al. [34] described the building geometry to include the window-wall ratio (WWR), building height and aspect ratio (L/M, L = length and M = width).

Before the evaluation of building retrofit measures, basic statistics accounting for the frequencies of building types and heat supply systems are pre-requisites for the design of building prototypes. Based on the availability of these statistics, three different methodological approaches are defined: "Real Example (ReEx) Building", "Real Average (ReAv) Building", and "Synthetical Average (SyAv) Building" [33]. The ReEx approach adopts experts' experience in the absence of statistical data to identify the building prototypes. On the other hand, the ReAv approach uses the mean statistical data of geometrical and construction features from a large-scale building survey to identify the archetypical building. In the SyAv approach, the prototypical building is a virtual building characterized by a statistical composite of the features detected in a class of buildings from a large building sample. The latter is commonly used in the circumstances with limited data availability or relatively great difficulty with acquiring data.

Retrospectively, building data statistics for developing prototypes were collated from small-scale survey of existing buildings. The first prototypical buildings were developed by Synergic Resource Corp using data from a small-scale survey in the 1980s to study the effect of occupancy on building energy consumption [35]. Also, this survey type was adopted to provide prototypical buildings as a benchmark for energy performance for non-domestic buildings in Ireland [36]. Nonetheless, the developed prototypes from a small-scale survey may not accurately and realistically represent the entire building stocks within the given region. This limitation has promoted the need for large-scale survey in developing building prototypes.

Large-scale surveys are more extensive and have a broader coverage of the sampled buildings, which tends to provide more specific prototypical buildings. Commercial building benchmark prototypes that adopted this survey type are listed in the literature [37, 38]. One major challenge of the large-scale survey is that a higher number of existing buildings make further analysis complex and challenging [39]. However, the selection of a reasonable range of existing buildings is essential to ensure a specific and accurate survey. A key selection criterion is that the randomly selected buildings based on a specific variable should exhibit the same proportion to that of the actual ratio.

1.2 Building typology in Shanghai, China

To develop energy-efficient measures, it is common practice to design prototypes for the most prominent existing building typologies. The design of prototypical buildings is typical for each geographical region and represents limited types of buildings within that region [26]. Focusing on Shanghai, office buildings account for more than 25% of the existing commercial building stocks [4]. Moreover, office buildings in Shanghai comprise of over 50% low-rise office building blocks. This type of commercial buildings has unique characteristics in terms of functions and building systems, which contribute a significant share in building energy consumption. Therefore, it is significant to develop prototypes that will serve as a guide to develop energy-efficient measures for low-rise office buildings in Shanghai.

Among the reviewed reference buildings developed in previous studies in China, there are limited studies conducted for office building blocks [2]. All studies were based on a small-scale survey and without a broad coverage of building samples. Specifically, there are no typical building model prototypes for existing low-rise office buildings in Shanghai at present. To fill this gap, this study proposes an approach to develop prototypical buildings for existing Shanghai low-rise office buildings employing large-scale survey. The establishment of this prototypical reference buildings will aid building owners, practitioners, and stakeholders understand building dynamics, evaluate and compare variations in building energy performance pertaining to their characteristics.

1.3 Research gaps and aims

As discussed earlier, the low-rise office buildings have a dominant share in the building energy consumption in Shanghai city. Therefore, low-rise office building typology was selected to represent the building stocks in Shanghai for the establishment of prototypical buildings. By so doing, the relationship between building characteristics and energy consumption is required. As such, this study aims at:

- to obtain the energy consumption for existing low-rise office building typologies via metered and simulated data,
- to correlate the building energy consumption with the existing low-rise office building characteristics, and
- to develop prototypes for existing low-rise office buildings using the major building characteristics from correlation and cluster analysis.

This study is based on the survey of existing low-rise office building blocks in Min Hang district, Shanghai. A survey involving 10 office parks with 136 randomly selected office buildings in this district was conducted.

2. Methodology for developing low-rise office building typologies in Shanghai

Generally, methodologies for developing low-rise office building prototypes require the definition of selected sample buildings characterized by their geometrical, thermo-physical features, and so on [40, 41]. The procedure for developing a reasonable low-rise office building prototypes consist of four main steps, as illustrated below:

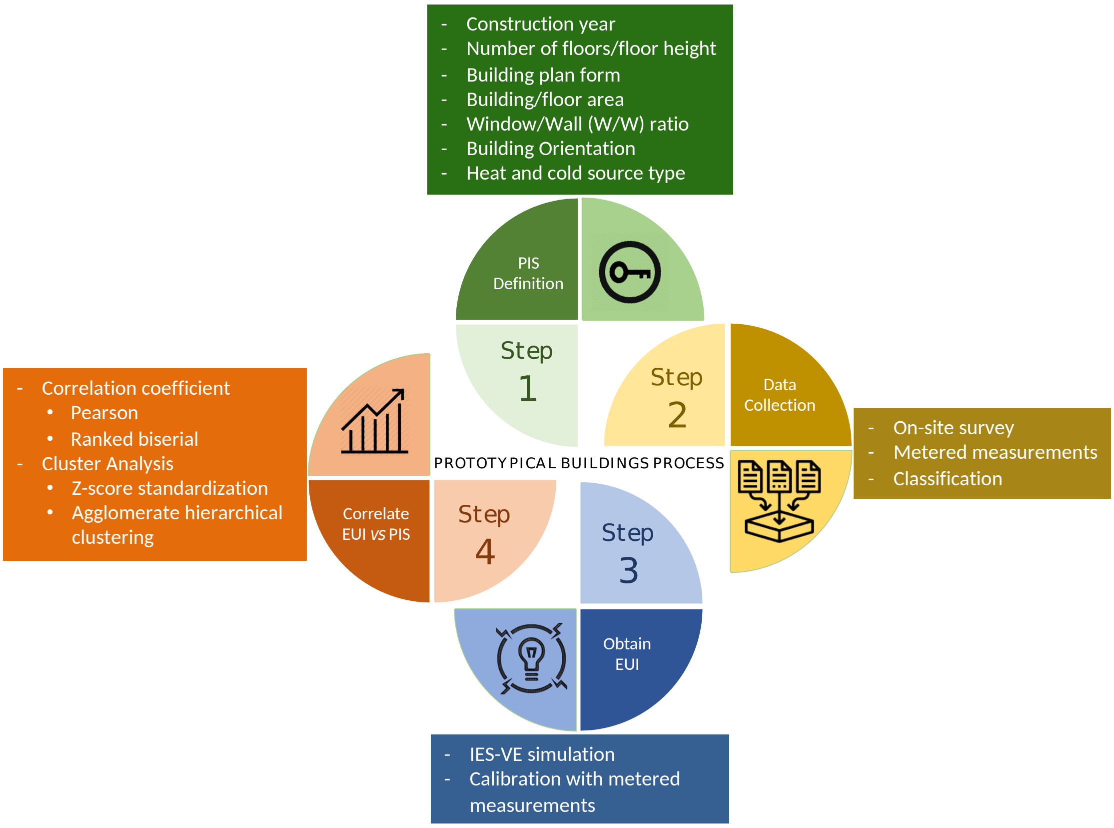


Fig. 1. Proceed for building prototype establishment

- **Step 1:** Definition of PIS to develop the relevant building prototype in the specific region.
- **Step 2:** Collation and processing of data collected from site survey and surrogate databases. Also, the classification of the surveyed low-rise office buildings using the defined PIS
- **Step 3:** Simulate and obtain the building energy consumption/energy use intensity (EUI) using the average statistical data of the building characteristics and measured simulation parameters. Here, the building energy consumption is based on the annual electricity consumption for heating, cooling and lighting [34, 42].
- **Step 4:** Statistical analysis of selected low-rise building stocks by performing the correlation between the building PIS and associated energy consumption/EUI. This step will aid in defining key PIS for the establishment of the prototypical buildings.

2.1 Proposed PIS of building energy consumption

The proposed PIS necessary for developing a building prototype are listed in Table 1. The effect of PIS was developed based on their impact on the building energy consumption/EUI. The selected indexes are based on the core attributes that describes the building characteristics, as discussed in Section 1.1. Emphasis was mainly on the building characteristics and not on other additional factors such as occupants' regime and behavior (including working overtime) or building equipment and facilities. This was aimed to reduce simulation complexities and comparison difficulties. These additional factors will broaden the variance in comparison, thus making it difficult to establish collective building prototypes. However, these factors were considered in subsequent studies involving the establishment of suitable retrofitting measures.

In this study, the PIS was limited to the regional architectural and environmental typologies, which includes building orientation, the number of floors, window/wall ratio, heat and cold source type, plan form and construction year. Due to the difficulty with access of data, as supported by ref. [26], data on building schedule, internal loading (occupant, lighting and equipment density) and detailed components of the HVAC systems were assumed to be constant using building standards and regulations from the Chinese government [43, 44]. Further details on these parameters are discussed in Section 2.3.

Table 1: Classification of low-rise office building prototypes

Classification	Core Indexes
Building Characteristics	*- Construction year* *(Building structure and thermophysical properties)* *- Number of floors/floor Height* *- Building plan form* *- Building area/Floor area* *- Window/wall ratio* *- Building orientation* *- Heat and cold source type*
Building Management and Control	*- Office Schedules and Activities* *- Human/Equipment/Lighting Density* *- Human Comfort Requirement*

2.1.1. Construction year (Building structure and thermo physical properties)

Buildings constructed within the same period usually demonstrate similar features and thermal property, particularly when backed up by government policies. Therefore, it is logical to use the construction year to categorize different architectural typology. In 2005, the Ministry of Construction and Urban Planning institute issued “Design standard for energy efficiency of public building”, and mandated buildings are built to achieve 50% energy reduction compared with buildings built with 1980 standards. The updated edition, “Design standard for energy efficiency of public buildings GB 50189-2015”, was released in 2016 and anticipates that new buildings reach 65% energy reduction of 1980’s baseline [43, 44].

Considering the release year of these design standards and the time frame for building construction and implementation of these standards, buildings were categorized into the construction years: before 2005, 2006 - 2015 and after 2016. Nonetheless, buildings built after 2016 are considered to have attained the regulation standards; hence does not require retrofitting measures. Therefore, this study focused on the two construction years: before 2005 (C1) and between 2006-2015 (C2). For emphasis, buildings in C1 and C2 were mainly built with brick or frame structure and concrete, respectively.

2.1.2. *Number of floors/floor height*

The number of floors is categorized based on the China Design Code for Office Building JCJ67-2006 [45]. According to this code, low-rise office buildings are considered to have heights below 24 m (or 1 – 6 floors according to the "Standard for energy consumption survey of civil buildings" [46]).

2.1.3. Building plan form

Another essential building characteristic is the building plan form [47, 48]. In order to ensure practical and accurate classification, three simplifying strategies were considered. First, all insignificant minor details such as surface articulation, attached features, and balconies were ignored. Second, buildings with complicated forms were virtually disassembled into smaller parts of simple forms, and these forms were considered separately. Finally, building forms should be represented parametrically by their plan dimensions of depth, length, and height (20). However, given that height has been earlier considered, the plan dimensions were limited to plane shapes, particularly square (S) and rectangular (R) shapes. Irregular building plane shapes that cannot be disassembled and represented parametrically were considered as other forms. In terms of the entire interior space, vertical traffic containing stairs or lift was ignored for low-rise office typology, because of their insignificant effect on the energy usage of low-rise office buildings

2.1.4. Building area/floor area

This building feature is another parameter that affects the building energy consumption, carbon emissions guide, and indoor thermal environment. The average floor area per building is selected as the primary form of floor area. The building area equals to the floor area multiplied by the number of floors. Here, the floor area is an exact estimate of obtained from the on-site measurement of the building dimension.

2.1.5. Window/wall (W/W) ratio

The window/wall (W/W) ratio is defined as the ratio of glazing area to floor area (G/F) of the building. Depending on the building characteristics and function, the W/W ratio might be disadvantageous to the building energy usage. Specifically, a large W/W ratio will gain extra heat in summer and lose additional heat during winter. As such, this index needs to be considered in defining prototypical buildings with consideration to the thermal properties of external building components. The classification of these indexes is based on GB50189-1980 for buildings before 2005 and GB50189-2005 for buildings after 2005. Description of the standard thermophysical characteristics for external building components regarding different W/W ratio is presented in Table 2. Based on these standards, the W/W ratio was classified into three groups: < 0.2 , 0.2 – 0.4, and > 0.4.

2.1.6. Building orientation

As building orientation has certain particular on the energy efficiency of buildings, this parameter was also considered as a performance index. In this study, the selected building orientations are limited to north-south (NS), 45^{o} south-east (S45^{o}E) and east-west (EW).

2.1.7. Heat and cold source type

The heat and cold sources have the most substantial contribution to building energy consumption and the most significant means of improving the thermal comfort of buildings. According to the distribution method of heat and cold sources, the indexes are divided into two types: decentralized and centralized.

Table 2. Summary of envelope thermal property with respect to window/wall ratio and construction year [43].

	External curtain wall (window/wall ratio)	**Overall Heat transfer coefficient ($W/m^2.K$)**		**Model thermal Property (C2 model) ($W/m^2.K$)**	**Model thermal property (C1 model) ($W/m^2.K$)**
		GB50189-2005	GB50189-1980	GB50189-2005	GB50189-1980
Roof		≤ 0.70	1.5	0.2714	3.1532
Wall (non-transparent curtain wall)		≤ 1.0	2	0.2451	2.4370
Exterior floor		≤ 1.0		0.2730	2.2183
External curtain wall	≤ 0.2	≤ 4.7	6.4	1.6	5.4380
	0.2-0.3	≤ 3.5	6.4		
	0.3-0.4	≤ 3.0	6.4		
	0.4-0.5	≤ 2.8	6.4		
	0.5-0.7	≤ 2.5	6.4		
Roof (transparent part)	≤ 0.02 (with exterior shading)	≤ 3.0			
	0.021-0.05	≤ 3.0			
	≤ 0.02 (without exterior shading)	≤ 3.0			
	0.021-0.05	≤ 3.0			
Floor (thermal resistance)		$R \geq 1.2\ m^2.K/W$		1.9987	3.3264
Underground exterior wall (thermal resistance)		$R \geq 1.2\ m^2.K/W$			

2.2 Sampling methodology

Vital performance data are collated from an on-site survey and analyzed to evaluate EUI using the Integrated Environmental Solutions Virtual Environment (IES-VE) simulation software. The survey was supported with GIS information retrieved from reliable online database, Baidu and Anjuke website. Anjuke Group is a distinguished real estate information service group that has branches in 31 cities. Its monthly independent access to the website has exceeded 69 million users. The data collection period is from August to October 2018.

Due to the difficulty in obtaining valuable data for all buildings, a simple random sampling method was used to select the building samples. The simple random sampling method is a miniature version of the population in which each element has the same probability of selection. The sampling fraction approach (denoted by $f = \frac{n}{N}$, where n is the size of the sample and N is the size of the population) was used to select the building samples [49]. Given that the construction year is the most accessible data, the buildings were randomly selected so that the ratio of the buildings across the construction years are similar to the actual building ratio across the same construction years.

2.3 Computational simulation

IES-VE simulation software was adopted to assess the annual electricity consumption for heating, cooling and lighting for the proposed prototypes. One-year simulation period with a monthly baseline model calibration was used. The simulation used the measured climatic data from low-rise office buildings within the considered construction years. The obtained simulation results are matched with the metered energy consumption data. The result also serves as a guide to provide energy statistics for buildings without energy data.

Data on building schedule, internal loading (occupant density, lighting and equipment density) and detailed components of the HVAC systems were set with reference to the Chinese building design standards and regulations [43, 44]. Due to limited data, these factors were assumed to be constant across the surveyed building samples, coupled with the aid to reduce analytical complexities. Typically, office operation days are about 200-250 days per year except for weekends and holidays. According to an average of 9 working hours per day including an hour lunch-break (09:00 – 18:00 hr), the operating time of each equipment and lights are about 1800-2250 hours per year. Concerning overtime, this varied significantly for different occupants in each building samples surveyed, and as such poses building classification challenges. Hence, for simplicity purpose, the building power consumption was assessed without consideration to working overtime.

The HVAC systems operate at a 50% capacity an hour (08:00 – 09:00 hr) prior to the working period and at full capacity during the office working hours (09:00 – 18:00 hr). Cooling is required around the summer period, which was assumed to be from May 1st to October 30th. Heating is required during the late autumn, throughout winter and early spring periods, which is assumed to be from November 1st to April 30th.

The implemented HVAC type was based on 'Public Building Energy Saving Design Standard, GB-50189' [43] and 'The Minimum Allowable Values of the Energy Efficiency and Energy Efficiency Grades for Unitary Air Conditioners, GB-19576-2004' [50]. This research focuses on existing low-rise office buildings completed before 2005 and between 2005 and 2014 in Shanghai. In these time periods, HVAC systems with constant air volume (CAV) air conditioning module is widely used and COP of 5.5 is recommended for low-rise office buildings according to the GB50189-2005 regulation. Also, the energy efficiency ratio (EER) of 3.2 is used according to the GB 19576-2004 regulation. A passive ventilation mechanism of opening the window was also adopted in the model simulation. The adopted regulations for simulating the HVAC system and the human comfort requirements during the working periods are presented in Table 3 and Table 4, respectively.

Human density was based on "Design Standards for energy efficiency of public buildings" [43]. The regulated average personal area of open office space is 4 m^2/person. Before 2005, lighting density was 25 W/m^2 and was reduced to 11 W/m^2 in 2005 regulation. Moreover, equipment density is 20 W/m^2. According to regulation [44], a modulating percentage was assigned in the simulation of daily human density and utilization of lighting and equipment systems. Typically, there are no human inside the building from 0:00 - 07:00 and 20:00 - 24:00. Hence, utilization of equipment will be 0%. From 8:00 - 9:00, people arrive at office and it is assumed that utilization of equipment is 50%. During the working period from 9:00 – 12:00 and 14:00 – 18:00, utilization will be 95% according to regulation. At lunch time (12:00 – 14:00), utilization will be 80%. Lastly, at closing hour (18:00 – 20:00), utilization will be 30%.

Table 3: Regulation for HVAC System [43, 50]

HVAC parameter	**Value**
Refrigerator COP	5.5
Energy efficiency ratio	3.2
Fan efficiency	0.7
Fresh air	8.3L/s/person
Fresh air temperature (°C)	14
Indoor design temperature (°C):	
- summer	22 - 28
- winter	16 - 22
Infiltration	0.2 ACH in perimeter area, 0 ACH in internal area

Table 4. Human comfort requirement

Requirement	**Summer**	**Winter**
HVAC temperature control	22 – 28 °C	16 - 22 °C
Humidity	50%	50%
Air Change Rate	1 ach^{-1}	1 ach^{-1}
Wind Sensitivity	0.5 ach^{-1}	0.5 ach^{-1}

3. Results and discussion

3.1 Data collection

Shanghai has 16 districts (Fig. 2(a)), each with a different share of non-residential building types and ranking (Table 5). In total, there are 62,231 × 10^4 m^2 of non-residential building area in Shanghai with office building blocks accounting for 8150 × 10^4 m^2. Due to the difficulty in studying this vast number of buildings, it is good practice to conduct studies on one specific district, particularly one with a high number of non-residential buildings. From Table 5, Pu Dong and Min Hang district are the first and second largest in terms of non-residential buildings with 14,013 and 6,414 m^2 building area. However, Pu Dong district was developed after the year 2000 and most buildings in this district are new and meet the design standards for energy-efficient buildings. Hence, it is reasonable to select Min Hang district (shown in Fig. 2(b)), for this research purpose with a high number of non-residential buildings and a wider variety of building years.

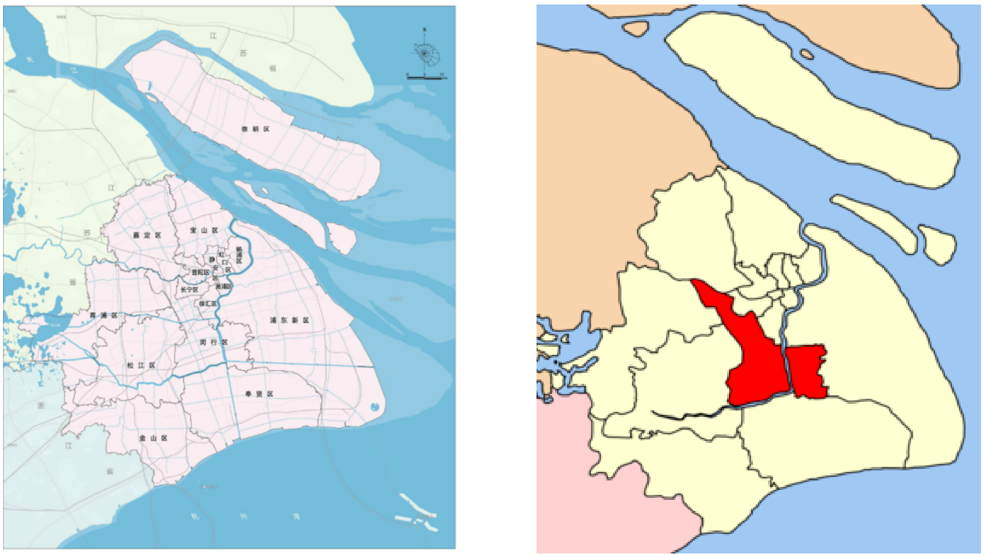


Fig. 2. Map of (a) districts in Shanghai, and (b) Min Hang District

Table 5. Summary of non-residential buildings and office buildings in Shanghai [51].

District	**Non-Residential Buildings (10^4 m^2)**	**Non-Residential Buildings Area Rank**	**Land Area (km^2)**	***Offices* Area (10^4 m^2)**	**Volume ratio (Density)**
Total	62 231		6340.50	8 150	0.09
Pu Dong New Area	14 013	1	1210.41	1 777	0.12
Huang Pu	2 035	13	20.46	758	0.99
Xu Hui	2 755	9	54.76	773	0.50
Chang Ning	1 724	14	38.30	585	0.45
Jing an	2 644	10	37.37	724	0.71
Pu Tuo	2 331	12	54.83	519	0.43
Hong Kou	1 410	15	23.48	448	0.60
Yang Pu	2 532	11	60.73	484	0.42
***Min Hang**	6 414	2	371.68	501	0.17
Bao Shan	4 227	5	270.99	290	0.16
Jia Ding	4 836	4	458.80	451	0.11
Jin Shan	3 081	8	586.05	159	0.53

Song Jiang	5 738	3	604.71	230	0.09
Qing Pu	3 780	6	675.54	164	0.06
Feng Xian	3 677	7	687.39	208	0.05
Chong Ming	1 033	16	1185.49	79	0.01

*District selected for sampling

To this regard, an on-site survey study was performed in Min Hang district to collect statistical data of existing office buildings. According to different building regulation standard released in 1980 and 2005, there are 408 and 1078 existing office buildings constructed before 2005 and between 2006-2015 respectively (see Table 6). Moreover, restricting the height of low-rise buildings to 24 meters (or 6 floors) [46], there are 1121 low-rise office buildings, which accounts for 75.4% of the total existing office buildings in Min Hang district of Shanghai.

Table 6. Existing office buildings in Min Hang district

Floors	**≤ 2005 (C1)**	**2006 - 2015 (C2)**	**Total**	**Percentage**
1-6 floors	296	825	1121	75%
≥ 7 floors	112	253	365	24%
Total	408	1078	1486	
Percentage	27%	73%		100%

Table 7. Breakdown of selected low-rise office buildings in Min Hang district

Floors	**≤ 2005 (C1)**	**2006 - 2015 (C2)**	**Total**	**Percentage**
1	-	-	**-**	**-**
2	3	-	**3**	**2%**
3	-	35	**35**	**26%**
4	4	71	**75**	**55%**
5	15	-	**15**	**11%**
6	1	7	**8**	**6%**
Total	**23**	**113**	**136**	**100%**
Percentage	**17%**	**83%**	**100%**	

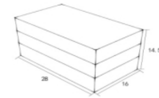
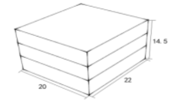
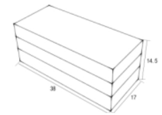
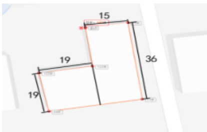
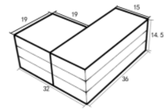
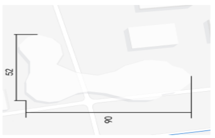
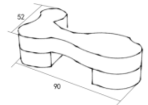
In order to sustain the ratio of buildings between C1 and C2, a total of 10 office parks containing 136 single low-rise office buildings, which accounted for about 10% of the existing low-rise office blocks in this district was surveyed in Shanghai. Table 7 shows a breakdown of the selected building samples. The locations of these parks are illustrated in Fig. 3, with their addresses, construction year, and building distribution presented in Table 8. According to the number of buildings within C1 and C2, the ratio was 23:113 ≈ 1.6:7.3, which is close to the actual ratio of 2.7:7.3 for the existing low-rise office buildings in the district. Taking Hong Xing International Square and Cao He Jing Office Park as examples of C2 and C1, Tables 9 and 10 present the specific building characteristics of the surveyed low-rise office buildings built within 2006 – 2015, and before 2005, respectively.

Fig. 3. Location of the selected office parks in Min Hang district

Table 8. The selected office parks in Min Hang District

No.	Name	Location	Construction Year	No. of Buildings (No. of floors)
1	Hong Xing International Square	No. 1969 Puxing Rd.	2014	32 (3 floors)
2	Pu Jiang Yi You Office Park	No. 1111 Hengnan Rd.	2014	18 (4 floors)
3	CIFI Pu Jiang International Square	No. 1650 Lianhang Rd.	2013	30 (4 floors)
4	Pu Jiang Science and Technology Park	No. 2388 Chenhang Rd.	2011	2 (3 floors), 2 (4 floors)
5	Cao He Jing Park	No. 2388 Chenhang Rd.	2004	13 (5 floors)
6	Vanke Zao City	No. 588 Beijiangju Rd.	2013	7 (6 floors)
7	Vanke VMO Park	No. 2049 Pujin Rd.	2011	1 (3 floors), 21 (4 floors)
8	Fawkes Chain Business Building (HongMei South Rd)	Hongmei South Rd, Meilong Town	2004	1 (6 floors), 1 (2 floors)
9	Fawkes Chain Business Building (Hu Guang East Rd)	No. 89 Huguang East Rd	2004	3 (2 floors), 1 (5 floors)
10	Fawkes Chain Business Building (Dou Zhuang Rd)	No.2755 Yindu Rd.	2005	4 (4 floors)

Table 9. Specific building characteristics of selected low-rise buildings built within 2006-2015 (All dimensions are in metric units).

Office park name	Hong Xing International Square								
Building number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
1.3.5.6.7.8.9.10.12.14.15.16.18.19.20.21.22.23		28	16	14.5	3	1344			18
2.4		22	20	14.5	3	1320			2
24.25.26.27.28.29.30.31		38	17	14.5	3	1938			8
13.17		36	32	14.5	3	2748			2
11		90	52	14.5	3	2575			1

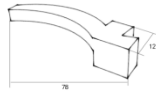
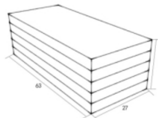
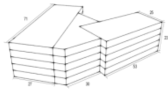
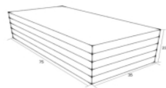
32		78	12	14.5	2	1550			1

Table 10. Specific characteristics of selected low-rise buildings built before 2005 (all dimensions are in metric units).

Office park name	Cao He Jing Office Park								
Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
2.3.4.5.6.7.8.9.10.11.12		63	27	23	5	8550			11
1		71	27	23	5	21225			1
13		75	35	23	5	13125			1

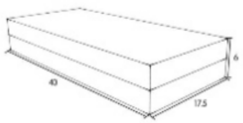
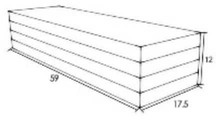
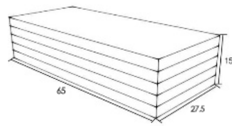
3.2. Building prototypes for low-rise office buildings in Shanghai and their associated energy consumption

Based on the aforementioned PIS, the surveyed buildings were classified using on-site survey data. For instance, according to the construction year, the buildings were divided into two categories C1 (≤ 2005) and C2 (2006 - 2015). Each period is characterized by a typical construction practice of the building envelope, particularly the employed materials and their thermophysical properties. Moreover, according to the building plan forms, existing low-rise office buildings before 2005 had a rectangle plan form; while buildings between 2006 - 2015 had both rectangle and square shape. Furthermore, classifications involving a minor number of buildings were ignored while developing the prototypes. Based on the number of buildings, seven typical classifications were identified. The typical classification included three buildings (B1, B2 and B3) from the construction year (C1), and four buildings (B1, B2, B3 and B4) from the construction year (C2).

- For C1:
  - C1B1: R plan form with 700 m^2 floor area, < 0.2 W/W ratio and 2 floors,
  - C1B2: R plan form with 1032.5 m^2 floor area, 0.2 - 0.4 W/W ratio and 4 floors,
  - C1B3: R plan form with 1787.5 m^2 floor area, 0.2 - 0.4 W/W ratio and 5 floors.
- For C2:
  - C2B1: R plan form with 555 m^2 floor area, 0.2 - 0.4 W/W ratio and 3 floors,
  - C2B2: R plan form with 408 m^2 floor area, > 0.4 W/W ratio and 4 floors,
  - C2B3: R plan form with 1809 m^2 floor area, > 0.4 W/W ratio and 6 floors,
  - C2B4: S plan form with 306 m^2 floor area, > 0.4 W/W ratio and 3 floors.

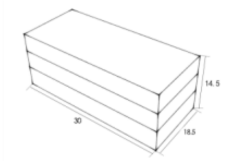
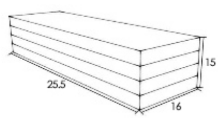
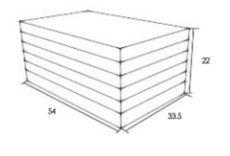
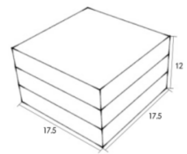
Further details of the typical buildings' characteristics are presented in Tables 11 and 12 for buildings under C1 and C2, respectively. Using IES-VE simulation software and metered data, the energy consumption and EUI for each building prototypes were obtained. In this study, EUI is defined as the ratio of building energy consumption to the building area. Simulation validation was conducted by comparing simulated energy results for prototypes C1B1 and C2B1 with actual metered data from the representative buildings. Simulated results were observed to be above 95% similar to actual data and demonstrate that the simulation tool is reliable for this study (Table 13).

Table 11. Low-rise office building prototypes before 2005 (C1)

PIS	Rectangle plan form		
	C1B1	**C1B2**	**C1B3**
No. of floors	2	4	5
Floor area* (m²)	700	1032.5	1787.5
Building area (m²)	1000-3000	3000-10000	3000-10000
Length (m)	40 (25-55)	59 (40-78)	65 (55-75)
Width (m)	17.5 (15-20)	17.5 (17-18)	27.5 (20-35)
Height (m)	6	12	15
Window/wall ratio	0.15	0.31	0.25
Sketch Model			
Representative buildings			
Yearly Energy Consumption	176.5 MWh/year	587.6 MWh/year	1181.6 MWh/year
Energy Use Intensity	126.06 kWh/m²	142.26 kWh/m²	132.20 kWh/m²

* the values are exact estimates obtained from the on-site survey of the selected building samples

Table 12. Low-rise office building prototypes between 2006 - 2015 (C2)

PIS	Rectangle plan form			Square plan form
	C2B1	**C2B2**	**C2B3**	**C2B4**
No. of floors	3	4	6	3
Floor area* (m^2)	555	408	1809	306
Building area (m^2)	1000-3000	1000-3000	>10000	1000-3000
Length (m)	30 (22-38)	25.5 (21-30)	54 (45-63)	17.5 (15-20)
Width (m)	18.5 (15-22)	16 (12-20)	33.5 (33-34)	17.5 (15-20)
Height (m)	14.5	15	22	12
Window/wall ratio	0.13	0.46	0.44	0.61
Sketch Model				
Representative buildings				
Yearly Energy Consumption	164.0 MWh/year	201.6 MWh/year	1266.8 MWh/year	132.4 MWh/year
Energy Use Intensity	98.50 kWh/m^2	123.53 kWh/m^2	116.71 kWh/m^2	144.23 kWh/m^2

* the values are exact estimates obtained from the on-site survey of the selected building samples

Table 13. Comparison of actual with simulated energy consumption for prototypes C2B1 and C1B1

Building	Prototype	Building floor	Actual energy consumed (kWh/yr)	Simulated energy consumed (MWh/yr)
Building 60 in Hong Xing Int'l Square	C2B1	2 and 3	113,921.30	
		1	42,309.74	
		Total	156,231.04	164.0 (95%)
Building 1 Fawkes Chain Business Building (Chun Shen Road)	C1B1	2	89,626.07	
		1	80,382.26	
		Total	170,008.33	176.5 (96%)

Using the proposed typical buildings, the simulated EUI is presented in Tables 11 and 12 for buildings under C1 and C2, respectively. The energy consumption for the typical buildings under C1, C1B1, C1B2 and C1B3, are 176.5 MWh, 587.6 MWh and 1181.6 MWh, respectively. Concerning C2, 164.0 MWh, 201.6 MWh, 1266.8 MWh and 132.4 MWh were estimated energy consumptions for C2B1, C2B2, C2B3 and C2B4, respectively. As a result, the building EUI within C1 varied from 126.06 - 142.26 kWh/m^2 with an average of 133.51 kWh/m^2, whereas for C2, the building EUI varied from 98.50 – 144.23 kWh/m^2 with an estimated average of 120.74 kWh/m^2. As expected, the building energy consumption after 2005 showed a significant decline when compared to that before 2005. The decline can be attributed to the upgrade in building envelope material with improved thermophysical properties.

3.3 Correlation between building performance index and energy consumption

Among the indexes mentioned above, the most influential on building EUI was investigated using correlation analysis of the data from the 136 office building samples. Table 14 presents the correlation analysis of the other building performance indexes (excluding building area) with respect to the building EUI. The most influential indexes from the analysis are then chosen for further building classifications. Pearson correlation coefficient served as the critical indicator for reflecting the degree of linear correlation between the indexes and the annual building EUI. However, for the dichotomous variables, a ranked Biserial correlation coefficient was used instead. Excel statistical tool, XLSTAT (version 2019.3.2) software was used for the computation of the correlation coefficients. Pearson and Biserial correlation coefficients are calculated using equations (1) and (2), respectively:

$$r = \frac{Cov(x,y)}{\sqrt{Var(x).Var(y)}} \tag{1}$$

$$r = \frac{(\overline{y_1} - \overline{y_2})\sqrt{P_1.P_2}}{S_y} \tag{2}$$

where Cov(x,y) is the covariance of x and y variables, Var(x) is the variance of x variable (classification index), and Var(y) is the variance of y variable (EUI), $\overline{y_1}$ and $\overline{y_2}$

are the mean values of y variables of the dichotomous groups 1 and 2, respectively; P_1 and P_2 are the proportion of groups 1 and 2, respectively; and S_y is the standard deviation of the population.

A confirmatory data analysis using two-tailed significance was computed using the f-test statistics:

$$f = \frac{\dfrac{\sum_{i=1}^{k} n_i(\overline{x_i} - \overline{X})^2}{(k-1)}}{\dfrac{\sum_{i=1}^{k}\sum_{j=1}^{n_i} (x_{ij} - \overline{x_i})^2}{(N-k)}} \qquad (3)$$

where n_i is the number of observations in the i^{th} sample group, $\overline{X}$ is the overall sample mean value of the data, k is the number of groups, x_{ij} is the j^{th} observation in the i^{th} sample group out of the k number of groups and N is the overall sample size. $\overline{x_i}$ is the mean value in the i^{th} sample group, and is defined as:

$$\overline{x_i} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad (4)$$

where x_i is the observed value of the i^{th} sample group, and n is the number of observations in the sample. Regarding this study, this data analysis includes a total of seven sample groups, each with six observations. The sample groups and observations represent the seven typical classes of building and the classification indexes, respectively.

Table 14. Correlation analysis of annual average building energy consumption per unit floor area of each index

Classification Index	**Average annual energy consumption per unit area**	
	Pearson correlation	**f-value (2-tailed sig.)**
Plan form	0.3684	0.2868
Number of floors	0.3075	0.5022
Heat/cold source	0.1773	0.7038
Construction year	0.6056	0.1149
Window/wall ratio	0.2006	0.6662
Building orientation	0.3684	0.2904

From Table 14, it is evident that the correlation coefficient reflects the following trend: construction year > plan form > building orientation > number of floors > window/wall ratio > heat or cold source type. The f-value of the significance test validates the trend. The f-value compares the joint effect of all the indexes together. A larger f-value denotes a more significant index. This result indicates that the building form and orientation, number of floors and W/W ratio are the major influencing factors with high significance for building energy consumption per unit area.

Furthermore, cluster analysis was adopted to characterize the indexes further. Clustering method of simplest and shortest distance was selected in this study while using Z-score for standardizing conversion values. The detailed steps of the cluster analysis are defined in reference [42] as follows:

Step 1. Calculate the distance between the samples using the squared Euclidean distance. This will aid generate the symmetric matrix shown in Table 15.

Step 2. The smallest non-zero element in the symmetric matrix was selected, and the two samples with the minimum distance denoted as D_{m1}. The two samples are then merged into one class, C_{m1}.

Step 3. Calculate the distance between C_{m1} and other samples; repeat the above steps until all samples are combined into one class, as shown in Table 16.

Table 15. Symmetric matrix of Euclidean distances

Index*	**1**	**2**	**3**	**4**	**5**	**6**
1	0	0.0128	0.0011	0.0030	6.4843	0.0032
2	0.0128	0	0.0120	0.0101	6.4723	0.0104
3	0.0011	0.0120	0	0.0022	6.4836	0.0023
4	0.0030	0.0101	0.0022	0	6.4815	0.0012
5	6.4843	6.4723	6.4836	6.4815	0	6.4820
6	0.0032	0.0104	0.0023	0.0012	6.4820	0

*1: Plan form, 2: Number of floors, 3: Window/wall ratio, 4: Heat and cold source type, 5: Construction year, 6: Building orientation.

The variable cluster analysis in Fig. 4 and Table 16 shows a 3-class and 4-class clustering of the indexes influencing the building EUI. The 4-class clustering indicates that plan form and window/wall (W/W) ratio formed the first cluster; heat and cold source type and building orientation formed the second cluster; while the number of floors and construction year individually formed the other two clusters. Under the 3-class clustering, plan form and window/wall ratio, heat and cold source type and building orientation are grouped under the first cluster; while the number of floors and construction year made up the second and third clusters, respectively.

The clustering analysis stipulates that construction year, number of floors, window-wall ratio and building orientation are the fundamental influencing factors, as depicted by the 4-class clustering. This finding corresponds with the correlation analysis presented earlier. In addition, it also matches with reported research findings from a similar city with the same climatic condition [42]. However, most buildings in this city are positioned in the N-S orientation, which makes the classification of buildings about this index (building orientation) to be less thorough. Therefore, it is logical to stipulate that the construction year, number of floors and window-wall ratio are the leading indexes for low-rise office building classification (as depicted by the 3-class clustering).

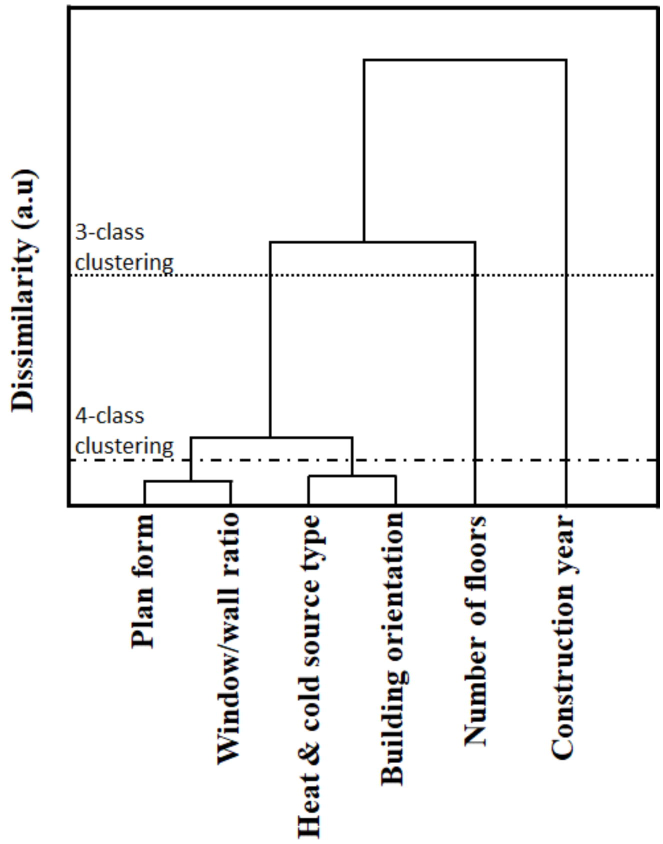


Fig. 4. Cluster analysis tree of office building indexes in Min Hang district, Shanghai

Table 16. Variable cluster analysis result for office building indexes in Min Hang district, Shanghai

Classification index	3-class clustering	4-class clustering
Plane form	1	1
Number of floors	2	3
Heat/cold source	1	2
Construction year	1	4
Window/wall ratio	3	1
Building orientation	1	2

3.4 Standard building assortment

Based on the statistical analysis, the 136 surveyed buildings were afterwards analyzed according to their construction year, number of floors, and W/W ratio, as shown in Table 17. The W/W ratio was classified into three: < 0.2 (W1), 0.2 – 0.4 (W2), and > 0.4 (W3). Table 17 illustrates that the number of floors for most buildings before 2005 ranged between 4 and 5 floors, which accounted for a total of *approx.* 83% of the surveyed buildings. About W/W ratio, most buildings before 2005 were categorized under W2, which accounted for *approx.* 87% of the surveyed buildings. In general, the analysis demonstrates that buildings with 4 and 5 floors and with W/W ratio of 02 – 0.4 were more prominent for low-rise offices building typologies within this period.

Between 2006-2015 (C2), most low-rise office buildings have 3 and 4 number of floors, which accounted for *approx.* 31% and 63% respectively of the surveyed buildings. Also, the W1 and W3 ratios were the more prominent W/W ratio within this construction year with a building share of *approx.* 27% and 72%, respectively. Overall, the statistical analysis within this period shows that most low-rise office buildings displayed a low or high W/W ratio with 3 and 4 number of floors.

Using the probability theory, an occurrence probability greater than 5% is considered as a significant probability of event [42]. Hence, an occurrence value above six buildings in Table 17 is the threshold for a significant-probability event in order to identify the prototypical buildings. Table 18 presents the breakdown of the prototypical buildings using significant probability theory. From Table 18, the most typical building prototypes are classified into four classes:

W1F3 = buildings with W/W ratio < 0.2 and 3 floors;
W2F5 = buildings with W/W ratio from 0.2 – 0.4 and 5 floors;
W3F4 = buildings with W/W ratio > 0.4 and with 4 floors; and
W3F6 = buildings with W/W ratio > 0.4 and with 6 floor

Adopting the probability theory, W2F5 was the only building prototype identified in the construction year C1, with an estimated 65% building share. However, for the C2 construction year, W1F3, W3F4 and W3F6 were the identified prototypical buildings with building shares of *approx.* 27%, 63% and 6%, respectively. Overall, the four prototypical buildings, W1F3, W2F5, W3F4 and W3F6 exhibited building shares of *approx.* 23%, 11%, 53% and 5%, respectively of the total surveyed buildings.

In summary, C1W2F5, C2W1F3, C2W3F4 and C2W3F6 are the four main prototypical buildings identified within Min Hang district of Shanghai. Lastly, a typical building representing each of this prototype is selected as the standard building, which will be adopted for subsequent studies and the development of adequate retrofit measures. The typical buildings representing each prototype is shown in Tables 19 - 22.

Table 17. Statistics of the building samples with regards to construction year, number of floors and W/W ratio.

No. of floors	Window-wall (W/W) ratio						Total
	< 2005			2006 - 2015			
	< 0.2	0.2 – 0.4	> 0.4	< 0.2	0.2 – 0.4	> 0.4	
2	2	1	-	-	-	-	**3**
3	-	-	-	31	1	3	**35**
4	-	4	-	-	-	71	**75**
5	-	15	-	-	-	-	**15**
6	-	-	1	-	-	7	**8**
Total	**2**	**20**	**1**	**31**	**1**	**81**	**136**

Table 18. Breakdown of prototypical buildings with regards to the number of floors and W/W ratio for different construction year.

Construction year	Prototypical buildings*				Others	Total
	W1F3	W2F5	W3F4	W3F6		
< 2005	-	15 (65.22%)	-	-	8 (34.78%)	**23 (100.00%)**
2006 - 2015	31 (27.43%)	-	71 (62.83%)	7 (6.20%)	4 (3.54%)	**113 (100.00%)**
Total	**31 (22.79%)**	**15 (11.03%)**	**71 (52.51%)**	**7 (5.15%)**	**12 (8.82%)**	**136 (100.00%)**

*W1F3 = buildings with W/W ratio < 0.2 and 3 floors; W2F5 = buildings with W/W ratio from 0.2 – 0.4 and 5 floors; W3F4 = buildings with W/W ratio > 0.4 and with 4 floors; and W3F6 = buildings with W/W ratio > 0.4 and with 6 floors.

Table 19. The typical building of C1W2F5: No. 2388 Chenhang Road.

Construction year	2004	**Window/wall ratio**	0.25
Plan form	Rectangular with 2.33 L/W ratio	**Heat and cold source type**	Dispersion
Structure type	Brick/frame structure	**Floor area**	1787.5 m^2
Height	15 m	**EUI**	132.20 kWh/m^2

Table 20. The typical building of C2W1F3: No. 1969 Puxing Rd.

Construction year	2014	**Window/wall ratio**	0.13
Plan form	Rectangular with 1.62 L/W ratio	**Heat and cold source type**	Dispersion
Structure type	Concrete structure	**Floor area**	555 m^2
Height	14.5 m	**EUI**	98.50 kWh/m^2

Table 21. The typical building of C2W3F4: No. 1650 Lianhang Road.

Construction year	2013	**Window/wall ratio**	0.46
Plan form	Rectangular with 1.11 L/W ratio	**Heat and cold source type**	Dispersion
Structure type	Concrete structure	**Floor area**	408 m^2
Height	15 m	**EUI**	123.53 kWh/m^2

Table 22. The typical building of C2W3F6: No. 588 Beijiangju Rd.

Construction year	2013	**Window/wall ratio**	0.44
Plan form	Rectangular with 1.61 L/W ratio	**Heat and cold source type**	Dispersion
Structure type	Concrete structure	**Floor area**	1809 m^2
Height	22 m	**EUI**	116.71 kWh/m^2

5. Conclusion and future research directions

To identify an efficient building retrofitting strategy for low-rise office buildings, it is crucial to establish prototypical buildings as representative standards for large building stocks. Here, a methodical approach is proposed to single out prototypes using core architectural indexes obtained from an on-site survey of 136 low-rise office buildings from a central urban area in Shanghai city. The proposed indexes include construction year, window/wall ratio, number of floors, plan form, building orientation, and the types of cold and heat sources. Based on collated data, the following conclusions were deduced:

1. Seven typical buildings are obtained after a detailed statistical analysis and classification using the proposed performance indexes. The typical buildings include six rectangle buildings and one single square building: three rectangular buildings built before 2005; three rectangle buildings built between 2006-2015; and one square building built between 2006-2015.

2. Using correlation analysis, the building plan form and orientation, number of floors and W/W ratio are the major influencing factors with high data significance for building energy consumption per unit area.

3. With agglomerate cluster analysis, the construction year, number of floors, window-wall ratio and building orientation are the fundamental cluster centroids. This analysis provides building indexes that should be used to determine prototypical buildings and can be applied for the study of existing buildings needing retrofitting.

4. Based on the most influencing indexes, four prototypical buildings were established: C2W1F3 (buildings with W/W ratio < 0.2 and 3 floors), C2W3F4 (buildings with W/W ratio > 0.4 and with 4 floors), and C2W3F6 (buildings with W/W ratio > 0.4 and with 6 floor), built between 2006-2015, and C1W2F5 (buildings with W/W ratio from 0.2 – 0.4 and 5 floors) built before 2005.

This research is part of a Phd project that aims to provide an integrated framework for green retrofitting package (GRP) for low-rise office buildings in Shanghai. It proposes a methodological approach for building classification, evaluation of energy performance based on building characteristics and identification of key performance index for building stocks that require energy conservative measures. This research has laid down a foundation that will guide the *ex-post* and *ex-ante* assessment of retrofit measures. Based on this, a decision-making toolkit can be further developed that can help urban managers and investors to identify the optimum retrofitting strategies.

Limitation and future development

In this study, a thorough assessment of the HVAC system, ventilation mechanism and varying working hour schedule was not conducted due to the limited preferences in China's building standards. Also, the building management and control index was not considered in the building prototype identification. These indexes were assumed on a general perspective across all building samples. In order to improve the efficacy of the methodology, further analysis incorporating specific details of these indexes is suggested.

Besides, the classification methodology developed in this study is not restricted to the 136 building samples in Min Hang district in Shanghai only but can be extended to a variety of building classification cases and also, the other districts and cities. It is worth mentioning that data from more buildings and other districts would add more robustness to the study. Also, this approach does not alleviate the process of data acquisition on building characteristics but rather provides a significant comparison platform for similar buildings.

In this study, we mainly focused on low-rise office buildings in Min Hang district of Shanghai. These buildings account for more than 75% of office buildings built before 2015. In order to achieve the set building standards beyond 2015, this work serves as a preliminary step for the establishment of representative building standards that will guide the design of optimal building retrofitting strategy for low-rise office buildings in Shanghai.

Furthermore, as most cities in China expand at a fast rate, new low-rise buildings built after 2016 will also reflect valuable information of newly developed urban zones, and thus are worth studying for energy retrofit strategies. This study will also aid in a better comparison and update of building prototypes in Shanghai.

Acknowledgment

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References

1. Ren, J., et al., *Influencing factors and energy-saving control strategies for indoor fine particles in commercial office buildings in six Chinese cities.* Energy and Buildings, 2017. **149**: p. 171-179.
2. Chen, H. and W.L. Lee, *Energy assessment of office buildings in China using LEED 2.2 and BEAM Plus 1.1.* Energy and Buildings, 2013. **63**: p. 129-137.
3. Lin, B., et al., *Investigation of winter indoor thermal environment and heating demand of urban residential buildings in China's hot summer – Cold winter climate region.* Building and Environment, 2016. **101**: p. 9-18.
4. Hong, Y., W. Deng, and C.I. Ezeh, *Low-rise Office Retrofit: Prerequisite for Sustainable and Green Buildings in Shanghai.* IOP Conference Series: Earth and Environmental Science, 2019. **281**: p. 012025.
5. Wang, Z., et al., *Residential heating energy consumption modeling through a bottom-up approach for China's Hot Summer–Cold Winter climatic region.* Energy and Buildings, 2015. **109**: p. 65-74.
6. Ichinose, T., L. Lei, and Y. Lin, *Impacts of shading effect from nearby buildings on heating and cooling energy consumption in hot summer and cold winter zone of China.* Energy and Buildings, 2017. **136**: p. 199-210.
7. Wang, Z., et al., *Rational selection of heating temperature set points for China's hot summer – Cold winter climatic region.* Building and Environment, 2015. **93**: p. 63-70.
8. Liu, X., G.J.D. Hewings, and S. Wang, *Evaluation on the impacts of the implementation of civil building energy efficiency standards on Chinese economic system and environment.* Energy and Buildings, 2009. **41**(10): p. 1084-1090.

9. Yin, R., P. Xu, and P. Shen, *Case study: Energy savings from solar window film in two commercial buildings in Shanghai.* Energy and Buildings, 2012. **45**: p. 132-140.
10. Carlson, K. and D.K.D. Pressnail, *Value impacts of energy efficiency retrofits on commercial office buildings in Toronto, Canada.* Energy and Buildings, 2018. **162**: p. 154-162.
11. Kontokosta, C.E., *Modeling the energy retrofit decision in commercial office buildings.* Energy and Buildings, 2016. **131**: p. 1-20.
12. Zheng, L. and J. Lai, *Environmental and economic evaluations of building energy retrofits: Case study of a commercial building.* Building and Environment, 2018. **145**: p. 14-23.
13. Eliopoulou, E. and E. Mantziou, *Architectural Energy Retrofit (AER): An alternative building's deep energy retrofit strategy.* Energy and Buildings, 2017. **150**: p. 239-252.
14. Xin, L., et al., *Effect of the energy-saving retrofit on the existing residential buildings in the typical city in northern China.* Energy and Buildings, 2018. **177**: p. 154-172.
15. Asdrubali, F., et al., *Energy and environmental payback times for an NZEB retrofit.* Building and Environment, 2019. **147**: p. 461-472.
16. Mora, D., et al., *Occupancy patterns obtained by heuristic approaches: Cluster analysis and logical flowcharts. A case study in a university office.* Energy and Buildings. **186**: p. 147-168.
17. Buttitta, G., W. Turner, and D. Finn, *Clustering of Household Occupancy Profiles for Archetype Building Models.* Energy Procedia. **111**: p. 161-170.
18. Diao, L., et al., *Modeling energy consumption in residential buildings: A bottom-up analysis based on occupant behavior pattern clustering and stochastic simulation.* Energy and Buildings. **147**: p. 47-66.
19. Ma, Z., R. Yan, and N. Nord, *A variation focused cluster analysis strategy to identify typical daily heating load profiles of higher education buildings.* Energy. **134**: p. 90-102.
20. Gaitani, N., et al., *Using principal component and cluster analysis in the heating evaluation of the school building sector.* Applied Energy. **87**(6): p. 2079-2086.
21. FilippÃ n, C., F. Ricard, and S. Flores Larsen, *Evaluation of heating energy consumption patterns in the residential building sector using stepwise selection and multivariate analysis.* Energy and Buildings. **66**: p. 571-581.
22. Wu, Y., et al., *Fast and Simple Preparation of Iron-Based Thin Films as Highly Efficient Water-Oxidation Catalysts in Neutral Aqueous Solution.* Angewandte Chemie International Edition, 2015. **54**(16): p. 4870-4875.
23. Deb, C. and S.E. Lee, *Determining key variables influencing energy consumption in office buildings through cluster analysis of pre- and post-retrofit building data.* Energy and Buildings. **159**: p. 228-245.
24. Gao, X. and A. Malkawi, *A new methodology for building energy performance benchmarking: An approach based on intelligent clustering algorithm.* Energy and Buildings. **84**: p. 607-616.
25. Gui, X.-c., et al., *The methodology of standard building selection for residential buildings in hot summer and cold winter zone of China based on architectural typology.* Journal of Building Engineering. **18**: p. 352-359.

26. Ye, Y., et al., *A methodology to create prototypical building energy models for existing buildings: A case study on U.S. religious worship buildings.* Energy and Buildings, 2019. **194**: p. 351-365.
27. Singh, S.P. and V. Bhat, *Performance evaluation of dual phase change material gypsum board for the reduction of temperature swings in a building prototype in composite climate.* Energy and Buildings, 2018. **159**: p. 191-200.
28. Briggs, R.S., D.B. Crawley, and J.S. Schliesing, *Energy requirements for office buildings. Volume 1, Existing buildings. GRI-90/0236.1 by Battelle, Pacific Northwest Laboratory, for Gas Research Institute.* 1992.
29. Ma, Z., et al., *Existing building retrofits: Methodology and state-of-the-art.* Energy and Buildings, 2012. **55**: p. 889-902.
30. Santamourisa, M., et al., *Energy conservation and retrofitting potential in Hellenic hotels.* Energy & Buildings, 1996. **24**(1): p. 65-75.
31. (TABULA), T.A.f.B.S.E.A., *TABULA building typologies - country pages*. 2016, Institut Wohnen und Umwelt GmbH http://episcope.eu/building-typology/country/ (Last accessed on 10th November, 2019): Institut Wohnen und Umwelt GmbH.
32. Monteiro, C.S., et al., *The Use of Multi-detail Building Archetypes in Urban Energy Modelling.* Energy Procedia, 2017. **111**: p. 817-825.
33. Ballarini, I., S.P. Corgnati, and V. Corrado, *Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project.* Energy Policy, 2014. **68**: p. 273-284.
34. Li, X., et al., *Developing urban residential reference buildings using clustering analysis of satellite images.* Energy and Buildings, 2018. **169**: p. 417-429.
35. Shahrestani, M., R. Yao, and G.K. Cook, *A review of existing building benchmarks and the development of a set of reference office buildings for England and Wales.* Intelligent Buildings International, 2014. **6**(1): p. 41-64.
36. Hernandez, P., K. Burke, and J.O. Lewis, *Development of energy performance benchmarks and building energy ratings for non-domestic buildings: An example for Irish primary schools.* Energy and buildings, 2008. **40**(3): p. 249-254.
37. Stocki, M., D.C. Curcija, and M.S. Bhandari, *The Development of Standardized Whole-Building Simulation Assumptions for Energy Analysis for a Set of Commercial Buildings.* ASHRAE Transactions, 2007. **113**(2).
38. Torcelini, P., et al., *DOE Commercial Building Benchmark Models. Proceeding in conference: 2008 ACEEE Summer Study on Energy Efficiency in Buildngs, Pacific Grove, California, Volume-pp: 4-305; 4-316*. 2008.
39. Ali, U., et al., *A data-driven approach for multi-scale building archetypes development.* Energy and Buildings, 2019. **202**: p. 109364.
40. Kragh, J. and K.B. Wittchen, *Development of two Danish building typologies for residential buildings.* Energy & Buildings, 2014. **68**(68): p. 79-86.
41. Ballarini, I., S.P. Corgnati, and V. Corrado, *Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project.* Energy Policy, 2014. **68**(68): p. 273-284.

42. Gui, X.-c., et al., *The methodology of standard building selection for residential buildings in hot summer and cold winter zone of China based on architectural typology.* Journal of Building Engineering, 2018. **18**: p. 352-359.
43. MOHURD, *Public Building Energy Saving Design Standard, GB-50189.* China National Code, 2005.
44. MOHURD, *Design standard for energy efficiency of public buildings GB50189-2015*, Ministry of Housing and Urban-Rural Development of the China, Editor. 2015: China.
45. Ministry of Housing and Urban-Rural Deveiopment of China, *China Design Code for Office Building JCJ67-2006.* 2006.
46. China Construction Department, *Standard for energy consumption survey of civil buildings JCJ/T 154-2007*, China Construction Department, Editor. 2007: China.
47. Peri, G., et al., *Environmentally Assessing Buildings Characterized by Complex Shape and Innovative Materials.* Advanced Materials Research, 2013. **664**: p. 409-414.
48. Wan, K.S.Y. and F.W.H. Yik, *Building design and energy end-use characteristics of high-rise residential buildings in Hong Kong.* Applied Energy, 2004. **78**(1): p. 19-36.
49. Ornstein, M., *A Companion to Survey Research*, K. Metzler, Editor. 2013, SAGE Publications Ltd: London DOI: 10.4135/9781473913943.
50. MOHURD, *The minimum allowable values of the energy efficiency and energy efficiency grades for unitary air conditioners, GB-19576-2004*, M.o.H.a.U.R. Development, Editor. 2005: China.
51. Bureau, S.M.S., *Shanghai Statistical Yearbook 1980-2017*, S.M.S. Bureau, Editor. 2017: Shanghai.

Conflict of Interest and Authorship Conformation Form

Please check the following as appropriate:

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Correlation between building characteristics and associated energy consumption: Prototyping low-rise office buildings in Shanghai

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Supporting Document

Table S1: Details of the measuring device for typical building, C1B1

Devices	Device Info	Product	MX2301
		Serial Number	20440432
		Firmware Version	100.47
		Manufacturer	Onset Computer Corp.
		Device Memory	131072
		Header Created	2018-10-16 16:12:33 +0800
	Deployment Info	Name	C1B1
		Location	31°04'53" N 121°30'23" E
		Group Name	Before 2005
		Deployment Number	2
		Wrap Enabled	NO
		Configure Time	2018-10-16 16:12:33 +0800
		Logging Interval	00 Hr 30 Min 00 Sec
		Statistics Sampling Interval	00 Hr 00 Min 15 Sec
		Battery at Launch (V)	3.58
Series: Temp, °C	Series Statistics	Samples	17568
		Max	33.54
		Min	5.54
		Avg	19.87
		Std Dev	6.79
		First Sample Time	2018-10-16 16:12:34 +0800
		Last Sample Time	2019-10-16 15:42:36 +0800
Series: Temp - Max, °C	Series Statistics	Samples	17568
		Max	34.75
		Min	9.67
		Avg	20.94
		Std Dev	5.02
		First Sample Time	2018-10-16 16:12:34 +0800
		Last Sample Time	2019-10-16 15:42:36 +0800
Series: Temp - Min, °C	Series Statistics	Samples	17568
		Max	31.50
		Min	0.90
		Avg	18.31
		Std Dev	8.41
		First Sample Time	2018-10-16 16:12:34 +0800
		Last Sample Time	2019-10-16 15:42:36 +0800
Series: RH, %	Series Statistics	Samples	17568
		Max	97.10

		Min	30.17
		Avg	60.21
		Std Dev	13.79
		First Sample Time	2018-10-16 16:12:34 +0800
		Last Sample Time	2019-10-16 15:42:36 +0800
Series: RH - Max, %	Series Statistics	Samples	17568
		Max	98.10
		Min	31.38
		Avg	68.12
		Std Dev	14.23
		First Sample Time	2018-10-16 16:12:34 +0800
		Last Sample Time	2019-10-16 15:42:36 +0800
Series: RH - Min, %	Series Statistics	Samples	17568
		Max	96.30
		Min	28.95
		Avg	53.06
		Std Dev	12.32
		First Sample Time	2018-10-16 16:12:34 +0800
		Last Sample Time	2019-10-16 15:42:36 +0800
Series: DewPt, °C	Series Statistics	Samples	17568
		Max	22.33
		Min	(7.73)
		Avg	7.75
		Std Dev	5.65
		First Sample Time	2018-10-16 16:12:34 +0800
		Last Sample Time	2019-10-16 15:42:36 +0800
Event Type:	Started		
Event Type:	Host Connect		
Event Type:	Button Down		
Event Type:	EOF		

Table S2: Details of the measuring device for typical building, C2B1

Devices	Device Info	Product	MX2301
		Serial Number	20440431
		Firmware Version	100.48
		Manufacturer	Onset Computer Corp.
		Device Memory	131072
		Header Created	2018-10-16 15:16:13 +0800

	Deployment Info	Name	C2B1
		Location	31°04'53" N 121°30'23" E
		Group Name	After 2005
		Deployment Number	2
		Wrap Enabled	NO
		Configure Time	2018-10-16 16:00:35 +0800
		Logging Interval	00 Hr 30 Min 00 Sec
		Statistics Sampling Interval	00 Hr 00 Min 15 Sec
		Battery at Launch (V)	3.50
Series: Temp, °C	Series Statistics	Samples	17568
		Max	34.74
		Min	6.54
		Avg	20.87
		Std Dev	6.79
		First Sample Time	2018-10-16 16:00:36 +0800
		Last Sample Time	2019-10-16 15:31:36 +0800
Series: Temp - Max, °C	Series Statistics	Samples	17568
		Max	36.12
		Min	10.93
		Avg	22.01
		Std Dev	8.44
		First Sample Time	2018-10-16 16:00:36 +0800
		Last Sample Time	2019-10-16 15:31:36 +0800
Series: Temp - Min, °C	Series Statistics	Samples	17568
		Max	32.82
		Min	1.92
		Avg	19.49
		Std Dev	5.04
		First Sample Time	2018-10-16 16:00:36 +0800
		Last Sample Time	2019-10-16 15:31:36 +0800
Series: RH, %	Series Statistics	Samples	17568
		Max	95.89
		Min	29.91
		Avg	59.21
		Std Dev	12.79
		First Sample Time	2018-10-16 16:00:36 +0800
		Last Sample Time	2018-12-21 21:00:36 +0800
Series: RH - Max, %	Series Statistics	Samples	17568
		Max	96.61

		Min	31.38
		Avg	66.22
		Std Dev	11.85
		First Sample Time	2018-10-16 16:00:36 +0800
		Last Sample Time	2019-10-16 15:31:36 +0800
Series: RH - Min, %	Series Statistics	Samples	17568
		Max	94.75
		Min	28.05
		Avg	51.34
		Std Dev	13.81
		First Sample Time	2018-10-16 16:00:36 +0800
		Last Sample Time	2019-10-16 15:31:36 +0800
Series: DewPt, °C	Series Statistics	Samples	17568
		Max	18.16
		Min	(2.85)
		Avg	9.92
		Std Dev	4.52
		First Sample Time	2018-10-16 16:00:36 +0800
		Last Sample Time	2019-10-16 15:31:36 +0800

Event Type:	Started
Event Type:	Host Connect
Event Type:	EOF

Table S3: Metered readings of the internal and external ambiance measurements for typical building, C1B1: Temperature (Temp), relative humidity (RH) and building energy consumption

Date Time, GMT+0800	**Internal Ambiance**		**External Ambiance**		**Energy Consumption, kWh**	
	Temp, °C	**RH, %**	**Temp, °C**	**RH, %**	**Daily**	**Monthly**
2018-10-16 0:00:00	19.16	64.27	23.73	54.12	529.58	
2018-10-17 0:00:00	20.35	64.54	23.56	48.96	528.38	
2018-10-18 0:00:00	18.69	59.15	23.58	47.94	532.16	
2018-10-19 0:00:00	19.00	54.55	23.03	41.05	513.41	
2018-10-20 0:00:00	18.03	64.45	23.93	49.38	509.14	
2018-10-21 0:00:00	19.94	70.82	22.65	56.35	336.45	
2018-10-22 0:00:00	19.37	84.88	22.86	66.13	314.29	
2018-10-23 0:00:00	18.02	74.75	22.62	61.86	501.95	
2018-10-24 0:00:00	20.13	71.36	24.15	56.13	543.03	
2018-10-25 0:00:00	21.06	68.41	23.94	55.40	549.84	
2018-10-26 0:00:00	22.68	60.48	24.30	52.76	542.14	
2018-10-27 0:00:00	17.57	37.15	23.36	29.60	518.91	
2018-10-28 0:00:00	17.16	41.72	23.23	33.86	426.69	

2018-10-29 0:00:00	18.75	46.17	24.59	35.47	330.34	
2018-10-30 0:00:00	19.75	62.73	25.01	47.20	536.98	
2018-10-31 0:00:00	18.19	56.14	24.10	40.88	554.40	
Average	**19.24**	**61.35**	**23.66**	**48.57**	**485.48**	**7,767.68**
2018-11-01 0:00:00	17.91	53.51	23.92	36.58	535.09	
2018-11-02 0:00:00	18.13	58.21	23.52	62.41	506.00	
2018-11-03 0:00:00	18.86	72.95	22.48	52.57	510.23	
2018-11-04 0:00:00	19.33	74.45	22.61	60.17	328.27	
2018-11-05 0:00:00	20.23	81.36	22.77	64.22	325.55	
2018-11-06 0:00:00	19.88	75.07	22.36	61.67	554.45	
2018-11-07 0:00:00	19.18	91.57	23.48	67.87	501.95	
2018-11-08 0:00:00	14.54	82.88	22.59	55.27	519.43	
2018-11-09 0:00:00	14.85	72.03	21.96	46.45	550.19	
2018-11-10 0:00:00	16.48	73.96	21.83	50.22	526.51	
2018-11-11 0:00:00	18.54	80.02	21.49	62.02	384.49	
2018-11-12 0:00:00	16.82	80.64	21.57	60.46	309.78	
2018-11-13 0:00:00	16.52	64.10	21.33	48.59	527.92	
2018-11-14 0:00:00	16.03	70.26	21.08	51.99	523.56	
2018-11-15 0:00:00	17.08	80.31	20.26	57.90	545.00	
2018-11-16 0:00:00	16.00	85.48	20.97	62.98	528.99	
2018-11-17 0:00:00	16.78	69.36	20.32	52.92	585.97	
2018-11-18 0:00:00	13.92	81.18	19.06	61.81	329.77	
2018-11-19 0:00:00	14.68	72.87	18.66	53.66	288.89	
2018-11-20 0:00:00	15.95	76.21	19.28	58.32	1243.38	
2018-11-21 0:00:00	15.56	91.31	19.69	67.91	0.00	
2018-11-22 0:00:00	14.63	68.05	19.07	50.00	367.89	
2018-11-23 0:00:00	14.32	67.35	19.81	47.37	577.09	
2018-11-24 0:00:00	16.61	68.15	20.72	49.70	576.13	
2018-11-25 0:00:00	16.37	79.99	21.02	56.97	465.87	
2018-11-26 0:00:00	17.74	82.41	20.96	63.07	358.71	
2018-11-27 0:00:00	17.20	77.78	20.80	60.78	585.49	
2018-11-28 0:00:00	15.32	79.19	20.10	57.96	592.17	
2018-11-29 0:00:00	15.66	78.63	20.67	56.38	592.16	
2018-11-30 0:00:00	16.46	80.65	20.88	60.92	541.22	
Average	**16.72**	**75.66**	**21.18**	**56.64**	**492.74**	**14,782.14**
2018-12-01 0:00:00	18.44	80.95	21.32	61.69	532.03	
2018-12-02 0:00:00	19.54	89.52	21.22	74.25	321.95	
2018-12-03 0:00:00	19.67	87.96	21.62	73.32	314.53	
2018-12-04 0:00:00	16.86	87.10	21.60	64.89	518.85	
2018-12-05 0:00:00	14.12	77.62	19.12	52.88	521.28	
2018-12-06 0:00:00	12.73	83.22	18.86	55.75	500.06	
2018-12-07 0:00:00	7.21	83.12	18.13	43.44	461.48	
2018-12-08 0:00:00	4.93	75.23	18.30	34.71	491.63	
2018-12-09 0:00:00	5.56	85.31	15.86	42.12	352.86	
2018-12-10 0:00:00	10.42	88.34	15.64	57.54	210.83	
2018-12-11 0:00:00	9.71	88.75	19.21	52.14	761.71	
2018-12-12 0:00:00	6.69	71.15	20.22	34.39	1362.92	

2018-12-13 0:00:00	6.59	63.80	15.82	34.96	969.21	
2018-12-14 0:00:00	8.60	65.32	15.30	40.82	1005.39	
2018-12-15 0:00:00	10.07	76.97	14.76	48.73	973.51	
2018-12-16 0:00:00	9.58	77.47	15.01	51.31	409.95	
2018-12-17 0:00:00	10.11	64.28	18.21	39.97	317.50	
2018-12-18 0:00:00	11.60	66.13	17.25	54.48	1034.55	
2018-12-19 0:00:00	13.38	67.18	18.47	43.77	837.93	
2018-12-20 0:00:00	13.21	80.94	16.56	60.89	593.46	
2018-12-21 0:00:00	13.72	87.06	21.00	52.60	548.06	
2018-12-22 0:00:00	14.20	88.95	18.08	64.62	554.45	
2018-12-23 0:00:00	12.11	74.01	16.60	55.14	412.56	
2018-12-24 0:00:00	11.13	67.21	16.89	48.01	310.94	
2018-12-25 0:00:00	11.86	78.16	16.78	54.82	571.11	
2018-12-26 0:00:00	10.56	90.93	17.21	62.16	564.20	
2018-12-27 0:00:00	7.77	74.24	15.57	46.97	718.72	
2018-12-28 0:00:00	4.54	58.46	14.65	34.27	1342.57	
2018-12-29 0:00:00	1.92	61.06	13.94	31.25	834.40	
2018-12-30 0:00:00	3.43	71.76	13.22	38.43	1194.09	
2018-12-31 0:00:00	4.80	76.95	16.85	34.66	288.89	
Average	**10.49**	**77.07**	**17.52**	**49.84**	**639.73**	**19,831.63**
2019-01-01 0:00:00	5.56	64.74	13.18	44.06	265.80	
2019-01-02 0:00:00	6.32	64.27	18.90	29.39	272.57	
2019-01-03 0:00:00	7.67	70.65	15.57	41.69	1572.15	
2019-01-04 0:00:00	10.30	87.20	14.40	59.32	1573.47	
2019-01-05 0:00:00	9.70	86.99	14.03	61.63	1213.39	
2019-01-06 0:00:00	8.64	88.00	14.54	59.76	472.36	
2019-01-07 0:00:00	8.33	86.58	19.57	46.94	319.92	
2019-01-08 0:00:00	7.98	77.06	16.44	45.97	1251.15	
2019-01-09 0:00:00	6.37	84.36	15.28	46.81	938.72	
2019-01-10 0:00:00	7.65	93.62	14.55	55.83	966.36	
2019-01-11 0:00:00	8.99	94.75	15.01	61.64	782.05	
2019-01-12 0:00:00	7.86	83.35	14.71	57.76	851.53	
2019-01-13 0:00:00	7.27	75.70	14.51	51.71	758.71	
2019-01-14 0:00:00	8.59	78.35	16.50	44.32	274.32	
2019-01-15 0:00:00	8.68	79.42	18.73	44.46	723.34	
2019-01-16 0:00:00	6.10	61.68	19.22	31.74	656.46	
2019-01-17 0:00:00	6.06	58.28	18.83	30.68	4139.30	
2019-01-18 0:00:00	8.32	69.37	15.82	38.13	0.00	
2019-01-19 0:00:00	9.71	79.10	20.40	39.45	0.00	
2019-01-20 0:00:00	8.42	68.11	15.88	42.63	0.00	
2019-01-21 0:00:00	6.60	59.61	14.89	35.68	0.00	
2019-01-22 0:00:00	8.23	53.35	18.13	32.50	0.00	
2019-01-23 0:00:00	8.93	53.48	17.45	32.13	90.94	
2019-01-24 0:00:00	9.97	63.97	16.26	38.57	722.50	
2019-01-25 0:00:00	9.55	70.76	16.08	44.53	529.55	
2019-01-26 0:00:00	5.99	55.05	16.94	33.32	523.70	
2019-01-27 0:00:00	7.41	62.22	15.71	35.41	758.92	
2019-01-28 0:00:00	8.10	74.09	20.62	36.46	269.16	

2019-01-29 0:00:00	9.04	74.63	18.41	41.82	462.95	
2019-01-30 0:00:00	8.42	77.47	17.39	54.73	457.25	
2019-01-31 0:00:00	7.37	81.73	15.54	52.79	433.64	
Average	**8.00**	**73.48**	**16.56**	**44.25**	**686.46**	**21,280.22**
2019-02-01 0:00:00	5.34	67.60	14.95	38.44	379.45	
2019-02-02 0:00:00	11.10	80.47	14.38	49.60	304.64	
2019-02-03 0:00:00	11.56	81.57	13.43	58.56	244.03	
2019-02-04 0:00:00	10.21	68.03	13.50	51.46	177.85	
2019-02-05 0:00:00	11.29	74.22	13.31	55.99	175.17	
2019-02-06 0:00:00	13.66	79.83	14.80	59.75	176.57	
2019-02-07 0:00:00	9.54	81.37	14.16	58.19	175.83	
2019-02-08 0:00:00	5.17	80.74	12.94	46.94	176.50	
2019-02-09 0:00:00	4.87	78.08	11.65	48.52	176.80	
2019-02-10 0:00:00	4.42	77.57	10.93	49.68	172.21	
2019-02-11 0:00:00	4.90	68.63	11.15	46.11	174.57	
2019-02-12 0:00:00	7.18	83.65	11.17	56.33	274.86	
2019-02-13 0:00:00	8.03	83.61	15.42	49.97	368.00	
2019-02-14 0:00:00	7.52	86.77	13.59	53.13	480.01	
2019-02-15 0:00:00	7.50	91.87	12.52	59.80	1026.67	
2019-02-16 0:00:00	6.39	72.60	12.08	44.32	1297.91	
2019-02-17 0:00:00	7.45	62.82	11.03	45.61	980.03	
2019-02-18 0:00:00	7.78	86.31	16.72	46.60	343.58	
2019-02-19 0:00:00	8.84	82.20	16.78	47.91	1464.35	
2019-02-20 0:00:00	7.24	85.73	17.49	44.81	864.25	
2019-02-21 0:00:00	7.84	87.75	17.36	47.09	1530.02	
2019-02-22 0:00:00	6.94	84.75	16.58	47.73	1368.36	
2019-02-23 0:00:00	7.76	72.65	14.44	45.70	888.67	
2019-02-24 0:00:00	11.03	60.22	14.40	42.46	338.64	
2019-02-25 0:00:00	8.94	75.64	16.01	46.70	230.69	
2019-02-26 0:00:00	10.93	74.37	19.12	48.66	856.91	
2019-02-27 0:00:00	9.71	84.31	17.32	48.47	728.57	
2019-02-28 0:00:00	11.42	71.30	16.13	51.95	860.97	
Average	**8.38**	**78.02**	**14.41**	**49.66**	**579.86**	**16,236.13**
2019-03-01 0:00:00	9.97	77.78	15.59	55.99	545.51	
2019-03-02 0:00:00	9.00	85.30	14.98	57.73	551.72	
2019-03-03 0:00:00	9.84	73.35	14.12	50.03	368.12	
2019-03-04 0:00:00	11.86	62.09	17.02	52.82	262.13	
2019-03-05 0:00:00	10.41	83.61	16.26	58.25	502.95	
2019-03-06 0:00:00	13.54	71.74	14.45	42.22	568.58	
2019-03-07 0:00:00	12.06	57.38	15.47	46.26	526.12	
2019-03-08 0:00:00	10.28	65.82	16.38	61.96	527.81	
2019-03-09 0:00:00	11.55	88.70	16.13	63.56	537.88	
2019-03-10 0:00:00	11.12	87.41	16.51	55.56	317.36	
2019-03-11 0:00:00	13.23	71.37	16.74	45.42	254.31	
2019-03-12 0:00:00	14.56	58.40	17.18	45.48	506.36	
2019-03-13 0:00:00	12.92	59.91	16.88	52.08	503.46	
2019-03-14 0:00:00	10.26	75.28	17.52	50.33	521.72	

2019-03-15 0:00:00	14.60	61.25	16.65	44.57	561.39	
2019-03-16 0:00:00	15.33	55.92	18.14	51.93	474.94	
2019-03-17 0:00:00	16.36	65.33	18.09	56.73	148.94	
2019-03-18 0:00:00	12.91	75.50	17.75	54.04	108.90	
2019-03-19 0:00:00	16.54	64.02	18.76	64.53	202.10	
2019-03-20 0:00:00	20.10	70.96	19.46	63.53	223.06	
2019-03-21 0:00:00	16.25	75.17	17.63	44.04	201.75	
2019-03-22 0:00:00	11.98	60.87	16.69	42.19	203.43	
2019-03-23 0:00:00	14.05	53.95	17.13	46.62	203.03	
2019-03-24 0:00:00	13.03	58.77	17.24	54.91	140.98	
2019-03-25 0:00:00	13.49	74.56	18.59	55.55	102.16	
2019-03-26 0:00:00	16.97	66.99	19.61	58.34	220.70	
2019-03-27 0:00:00	16.62	72.88	21.51	60.86	234.17	
2019-03-28 0:00:00	16.23	82.31	19.58	62.09	213.97	
2019-03-29 0:00:00	16.99	74.65	19.47	56.45	234.11	
2019-03-30 0:00:00	15.73	69.11	18.47	36.29	232.99	
2019-03-31 0:00:00	15.20	41.20	18.12	35.56	129.52	
Average	**13.64**	**69.08**	**17.36**	**52.45**	**333.23**	**10,330.17**
2019-04-01 0:00:00	15.77	46.15	18.07	46.88	101.81	
2019-04-02 0:00:00	15.28	56.43	18.21	53.57	220.12	
2019-04-03 0:00:00	17.41	65.45	19.03	59.77	239.70	
2019-04-04 0:00:00	14.61	79.07	18.31	59.05	240.41	
2019-04-05 0:00:00	20.24	62.45	19.26	60.23	237.54	
2019-04-06 0:00:00	21.21	62.77	20.11	62.82	111.75	
2019-04-07 0:00:00	23.49	59.93	22.76	64.38	104.01	
2019-04-08 0:00:00	23.10	68.51	23.15	74.39	106.95	
2019-04-09 0:00:00	22.07	77.81	21.19	47.16	210.83	
2019-04-10 0:00:00	12.81	71.77	19.75	47.37	216.77	
2019-04-11 0:00:00	13.35	64.49	19.35	48.15	199.44	
2019-04-12 0:00:00	15.43	61.71	19.83	53.04	218.81	
2019-04-13 0:00:00	18.14	62.74	20.08	60.56	223.29	
2019-04-14 0:00:00	17.79	68.74	19.49	42.81	98.01	
2019-04-15 0:00:00	17.99	53.89	19.20	54.02	105.37	
2019-04-16 0:00:00	17.73	64.50	20.77	61.15	202.27	
2019-04-17 0:00:00	20.53	69.44	22.22	52.38	161.55	
2019-04-18 0:00:00	24.09	63.36	22.19	70.50	190.49	
2019-04-19 0:00:00	23.64	72.86	22.15	74.05	203.94	
2019-04-20 0:00:00	22.60	74.83	22.23	77.74	166.43	
2019-04-21 0:00:00	22.40	78.38	22.15	77.87	103.27	
2019-04-22 0:00:00	20.35	92.62	23.94	78.80	101.48	
2019-04-23 0:00:00	24.21	80.56	24.83	77.33	212.68	
2019-04-24 0:00:00	23.39	81.50	24.57	67.25	201.24	
2019-04-25 0:00:00	21.79	76.34	23.32	53.71	224.34	
2019-04-26 0:00:00	16.15	74.57	21.24	47.74	214.95	
2019-04-27 0:00:00	17.15	62.78	21.94	64.95	223.36	
2019-04-28 0:00:00	18.30	80.14	22.19	69.85	110.11	
2019-04-29 0:00:00	18.95	84.73	21.45	66.82	197.18	
2019-04-30 0:00:00	16.93	81.76	20.27	58.61	186.93	

Average	**19.23**	**70.01**	**21.11**	**61.10**	**177.83**	**5,335.03**
2019-05-01 0:00:00	20.21	66.81	21.81	60.73	193.25	
2019-05-02 0:00:00	21.37	49.42	21.06	42.13	91.27	
2019-05-03 0:00:00	22.07	45.23	21.64	40.65	86.35	
2019-05-04 0:00:00	23.66	40.81	22.23	56.58	82.91	
2019-05-05 0:00:00	22.50	59.95	21.38	47.00	89.74	
2019-05-06 0:00:00	19.17	56.58	22.19	35.84	185.44	
2019-05-07 0:00:00	18.91	41.01	22.55	45.64	195.31	
2019-05-08 0:00:00	20.24	50.94	23.55	50.15	196.93	
2019-05-09 0:00:00	22.16	59.78	24.11	53.71	190.30	
2019-05-10 0:00:00	23.24	60.11	24.19	53.69	168.33	
2019-05-11 0:00:00	25.36	57.20	25.01	54.34	213.62	
2019-05-12 0:00:00	24.43	56.54	24.57	57.51	121.95	
2019-05-13 0:00:00	20.80	68.41	24.42	61.21	138.59	
2019-05-14 0:00:00	21.27	70.46	23.11	67.66	211.81	
2019-05-15 0:00:00	21.16	83.92	24.57	73.94	189.49	
2019-05-16 0:00:00	23.32	81.96	25.23	75.56	237.21	
2019-05-17 0:00:00	24.35	78.27	24.60	73.26	243.63	
2019-05-18 0:00:00	24.06	74.24	24.07	67.78	245.80	
2019-05-19 0:00:00	22.72	78.54	25.01	71.46	128.07	
2019-05-20 0:00:00	22.55	63.43	25.14	46.10	114.77	
2019-05-21 0:00:00	18.09	62.95	24.79	36.56	180.29	
2019-05-22 0:00:00	18.22	59.66	26.41	43.51	187.03	
2019-05-23 0:00:00	17.68	67.16	27.06	46.39	219.71	
2019-05-24 0:00:00	17.95	78.64	27.48	44.70	234.48	
2019-05-25 0:00:00	20.12	73.72	26.72	61.37	417.07	
2019-05-26 0:00:00	24.01	65.47	25.83	75.95	298.15	
2019-05-27 0:00:00	23.23	60.28	26.00	69.79	127.20	
2019-05-28 0:00:00	22.25	63.59	25.92	40.13	374.99	
2019-05-29 0:00:00	21.94	68.34	26.44	39.99	205.69	
2019-05-30 0:00:00	20.76	52.94	25.81	43.12	200.43	
2019-05-31 0:00:00	23.99	64.93	23.75	53.46	224.11	
Average	**21.67**	**63.27**	**24.41**	**54.51**	**193.35**	**5,993.91**
2019-06-01 0:00:00	19.27	64.59	20.02	48.26	368.24	
2019-06-02 0:00:00	23.63	52.08	23.96	39.53	205.11	
2019-06-03 0:00:00	21.95	45.16	20.55	41.50	224.70	
2019-06-04 0:00:00	23.39	39.24	21.65	58.14	189.58	
2019-06-05 0:00:00	23.96	65.68	23.53	44.55	230.74	
2019-06-06 0:00:00	18.30	54.89	21.75	36.56	365.24	
2019-06-07 0:00:00	18.02	40.61	21.56	46.77	387.91	
2019-06-08 0:00:00	22.14	52.73	25.18	46.18	379.50	
2019-06-09 0:00:00	21.08	58.00	22.44	57.19	372.98	
2019-06-10 0:00:00	22.39	57.04	23.20	56.30	352.71	
2019-06-11 0:00:00	27.04	59.10	26.93	50.16	419.44	
2019-06-12 0:00:00	23.78	55.85	23.78	61.07	276.68	
2019-06-13 0:00:00	20.18	68.73	23.00	60.49	246.53	
2019-06-14 0:00:00	23.28	71.79	25.22	63.46	406.00	

2019-06-15 0:00:00	20.27	83.52	23.59	75.45	376.34	
2019-06-16 0:00:00	22.67	80.90	24.61	44.46	484.05	
2019-06-17 0:00:00	26.45	83.51	25.91	65.26	478.99	
2019-06-18 0:00:00	22.98	73.61	22.87	72.89	489.96	
2019-06-19 0:00:00	21.91	77.26	23.42	74.95	375.54	
2019-06-20 0:00:00	24.27	60.99	25.66	43.15	227.43	
2019-06-21 0:00:00	16.89	61.79	23.84	38.72	351.55	
2019-06-22 0:00:00	17.20	59.15	25.56	44.51	358.27	
2019-06-23 0:00:00	19.30	69.82	29.07	43.46	436.95	
2019-06-24 0:00:00	16.37	77.63	26.51	45.27	457.20	
2019-06-25 0:00:00	19.20	72.45	25.55	64.26	824.68	
2019-06-26 0:00:00	25.94	68.64	28.04	70.28	598.86	
2019-06-27 0:00:00	22.21	59.49	25.42	72.93	249.59	
2019-06-28 0:00:00	22.11	61.33	25.23	42.59	775.24	
2019-06-29 0:00:00	23.98	68.57	27.11	35.95	526.79	
2019-06-30 0:00:00	19.65	54.40	24.83	43.90	456.03	
Average	**21.66**	**63.29**	**24.33**	**52.94**	**396.43**	**11,892.84**
2019-07-01 0:00:00	28.42	55.94	24.24	39.06	159.65	
2019-07-02 0:00:00	29.25	41.78	24.67	37.49	399.31	
2019-07-03 0:00:00	32.06	38.17	26.06	33.25	425.53	
2019-07-04 0:00:00	33.81	32.23	26.46	46.24	531.70	
2019-07-05 0:00:00	31.77	52.58	26.74	39.45	498.93	
2019-07-06 0:00:00	28.57	44.59	27.06	29.55	418.18	
2019-07-07 0:00:00	28.34	32.78	27.17	36.64	160.62	
2019-07-08 0:00:00	29.74	41.66	28.09	41.48	108.83	
2019-07-09 0:00:00	31.47	49.56	28.05	45.56	422.63	
2019-07-10 0:00:00	32.95	49.86	29.11	45.53	502.70	
2019-07-11 0:00:00	35.77	45.76	30.44	43.78	445.34	
2019-07-12 0:00:00	34.76	45.53	30.19	47.27	341.69	
2019-07-13 0:00:00	31.79	52.98	28.78	47.12	154.39	
2019-07-14 0:00:00	31.57	56.44	29.74	56.01	148.47	
2019-07-15 0:00:00	31.92	65.68	30.08	58.37	399.64	
2019-07-16 0:00:00	33.48	62.08	30.32	63.83	429.43	
2019-07-17 0:00:00	35.37	65.30	29.92	57.64	524.99	
2019-07-18 0:00:00	34.27	61.51	30.08	55.29	496.63	
2019-07-19 0:00:00	33.53	62.86	30.73	57.59	431.89	
2019-07-20 0:00:00	32.85	50.25	30.17	37.79	147.14	
2019-07-21 0:00:00	28.73	46.43	30.75	30.43	609.08	
2019-07-22 0:00:00	28.50	44.64	31.77	34.30	836.12	
2019-07-23 0:00:00	28.42	51.56	32.78	39.18	745.27	
2019-07-24 0:00:00	28.13	59.72	32.82	36.04	925.95	
2019-07-25 0:00:00	30.75	55.44	31.86	52.20	557.30	
2019-07-26 0:00:00	34.65	52.69	31.25	61.07	697.46	
2019-07-27 0:00:00	33.72	49.34	31.93	56.85	159.66	
2019-07-28 0:00:00	33.42	49.89	31.53	33.34	148.61	
2019-07-29 0:00:00	32.69	52.08	31.94	32.45	916.34	
2019-07-30 0:00:00	30.76	43.34	31.12	34.37	861.20	
2019-07-31 0:00:00	35.02	51.31	28.95	44.69	969.48	

Average	**31.82**	**50.45**	**29.51**	**44.32**	**470.14**	**14,574.19**
2019-08-01 0:00:00	30.88	52.27	27.34	36.76	711.22	
2019-08-02 0:00:00	32.13	39.32	26.58	33.67	558.13	
2019-08-03 0:00:00	33.59	36.05	27.28	31.67	862.47	
2019-08-04 0:00:00	34.47	33.14	27.80	45.81	135.98	
2019-08-05 0:00:00	32.90	49.95	28.29	36.92	732.30	
2019-08-06 0:00:00	29.48	43.09	27.86	28.05	586.09	
2019-08-07 0:00:00	29.44	31.38	28.00	35.13	620.45	
2019-08-08 0:00:00	30.66	39.43	28.42	40.67	613.36	
2019-08-09 0:00:00	32.42	45.87	28.86	44.50	694.18	
2019-08-10 0:00:00	33.82	48.16	30.23	43.65	175.78	
2019-08-11 0:00:00	36.12	45.99	30.64	44.49	140.74	
2019-08-12 0:00:00	34.94	46.27	29.57	45.09	757.04	
2019-08-13 0:00:00	32.00	54.48	30.10	48.08	585.00	
2019-08-14 0:00:00	31.68	56.84	29.76	54.69	742.27	
2019-08-15 0:00:00	32.08	65.46	30.26	39.30	646.82	
2019-08-16 0:00:00	33.78	64.85	29.84	61.19	602.11	
2019-08-17 0:00:00	35.29	65.59	29.72	59.33	501.59	
2019-08-18 0:00:00	34.26	61.12	29.30	56.03	324.45	
2019-08-19 0:00:00	32.45	61.05	28.45	60.06	848.88	
2019-08-20 0:00:00	31.65	52.07	29.22	39.71	878.87	
2019-08-21 0:00:00	27.51	48.83	29.70	31.20	778.24	
2019-08-22 0:00:00	27.32	47.37	30.98	35.55	735.43	
2019-08-23 0:00:00	26.84	54.00	31.80	39.42	557.52	
2019-08-24 0:00:00	27.01	62.16	31.45	37.74	599.44	
2019-08-25 0:00:00	29.88	59.02	31.27	53.53	193.37	
2019-08-26 0:00:00	33.30	54.79	30.67	63.37	1128.65	
2019-08-27 0:00:00	33.23	49.99	31.03	60.35	820.55	
2019-08-28 0:00:00	32.12	50.69	29.40	33.23	1236.26	
2019-08-29 0:00:00	30.88	58.95	29.96	33.90	593.94	
2019-08-30 0:00:00	29.12	46.26	29.50	40.67	543.19	
2019-08-31 0:00:00	32.56	54.89	26.56	46.12	243.78	
Average	**31.74**	**50.95**	**29.35**	**43.87**	**617.68**	**19,148.10**
2019-09-01 0:00:00	28.27	56.59	24.25	40.39	199.35	
2019-09-02 0:00:00	30.37	40.34	24.30	36.73	716.11	
2019-09-03 0:00:00	31.46	40.05	25.63	34.75	398.66	
2019-09-04 0:00:00	32.46	35.21	26.66	48.95	667.41	
2019-09-05 0:00:00	29.58	56.51	25.20	41.68	836.97	
2019-09-06 0:00:00	26.48	49.65	25.19	31.09	688.84	
2019-09-07 0:00:00	26.13	36.66	24.63	40.28	531.62	
2019-09-08 0:00:00	27.74	45.69	25.93	46.22	235.53	
2019-09-09 0:00:00	29.57	52.64	26.38	49.48	918.82	
2019-09-10 0:00:00	30.67	52.62	27.14	49.53	973.64	
2019-09-11 0:00:00	33.07	50.04	26.40	47.30	1115.49	
2019-09-12 0:00:00	31.04	53.40	26.17	53.78	940.77	
2019-09-13 0:00:00	27.84	64.13	25.91	54.97	551.03	
2019-09-14 0:00:00	27.48	63.33	25.32	66.21	566.63	

2019-09-15 0:00:00	28.08	76.11	25.47	68.39	602.67	
2019-09-16 0:00:00	29.68	77.28	26.63	72.27	768.99	
2019-09-17 0:00:00	31.37	78.61	26.63	66.87	874.04	
2019-09-18 0:00:00	29.36	75.27	24.81	67.10	856.38	
2019-09-19 0:00:00	28.46	75.60	25.70	71.94	656.46	
2019-09-20 0:00:00	27.75	60.33	25.47	44.98	758.00	
2019-09-21 0:00:00	23.73	61.00	25.81	36.19	292.32	
2019-09-22 0:00:00	23.40	59.76	26.81	41.10	294.87	
2019-09-23 0:00:00	23.20	65.59	27.24	47.17	374.33	
2019-09-24 0:00:00	22.05	79.60	26.36	45.25	390.11	
2019-09-25 0:00:00	24.38	74.98	26.19	63.18	510.80	
2019-09-26 0:00:00	28.50	67.43	25.76	76.82	379.83	
2019-09-27 0:00:00	28.15	59.83	26.01	71.12	416.18	
2019-09-28 0:00:00	26.91	65.11	25.32	40.23	279.38	
2019-09-29 0:00:00	25.99	73.09	24.42	42.73	477.19	
2019-09-30 0:00:00	23.97	58.00	23.51	45.23	489.80	
Average	**27.90**	**60.15**	**25.71**	**51.40**	**592.07**	**17,762.23**
2019-10-01 0:00:00	23.67	72.91	19.25	50.10	242.82	
2019-10-02 0:00:00	25.26	52.90	19.80	46.48	239.98	
2019-10-03 0:00:00	26.36	49.99	20.13	44.06	239.20	
2019-10-04 0:00:00	27.70	43.50	21.86	59.30	209.23	
2019-10-05 0:00:00	24.57	72.30	19.90	53.47	192.14	
2019-10-06 0:00:00	21.59	65.15	19.99	39.42	218.57	
2019-10-07 0:00:00	21.25	47.73	19.53	51.06	192.86	
2019-10-08 0:00:00	22.49	57.33	20.33	58.02	333.18	
2019-10-09 0:00:00	24.55	68.20	21.58	61.78	387.92	
2019-10-10 0:00:00	25.20	70.11	21.24	64.57	433.22	
2019-10-11 0:00:00	26.77	66.33	20.93	61.38	416.70	
2019-10-12 0:00:00	26.45	68.32	21.12	66.31	362.36	
2019-10-13 0:00:00	22.70	84.36	20.93	69.02	294.82	
2019-10-14 0:00:00	22.98	86.84	20.92	81.79	452.96	
2019-10-15 0:00:00	21.87	87.56	19.18	89.24	434.89	
2019-10-16 0:00:00	23.91	91.59	19.93	96.61	423.20	
Average	**24.21**	**67.82**	**20.41**	**62.04**	**317.13**	**5,074.06**
Total						**170,008.33**

Table S4: Metered readings of the internal and external ambiance measurements for typical building, C2B1: Temperature (Temp), relative humidity (RH) and building energy consumption

Date Time, GMT+0800	Internal Ambiance		External Ambiance		Energy Consumption, kWh	
	Temp, °C	RH, %	Temp, °C	RH, %	Daily	Monthly
2018-10-16 0:00:00	17.96	68.37	22.38	55.71	483.84	
2018-10-17 0:00:00	18.85	65.19	22.40	51.60	487.20	
2018-10-18 0:00:00	18.19	60.98	22.74	48.60	493.36	

2018-10-19 0:00:00	17.70	57.42	22.48	42.90	487.20	
2018-10-20 0:00:00	18.53	65.62	22.38	51.18	469.84	
2018-10-21 0:00:00	18.94	72.56	22.19	58.83	311.92	
2018-10-22 0:00:00	17.87	88.70	22.18	68.32	288.96	
2018-10-23 0:00:00	19.22	75.91	22.09	62.35	465.36	
2018-10-24 0:00:00	19.13	73.40	22.57	58.80	502.88	
2018-10-25 0:00:00	19.73	69.71	22.75	57.19	509.60	
2018-10-26 0:00:00	20.59	61.99	22.99	55.36	504.00	
2018-10-27 0:00:00	17.22	38.21	22.52	30.52	479.92	
2018-10-28 0:00:00	18.15	43.72	22.48	34.48	403.76	
2018-10-29 0:00:00	19.49	46.57	23.11	36.37	305.20	
2018-10-30 0:00:00	19.24	64.25	23.53	47.62	495.60	
2018-10-31 0:00:00	17.99	57.16	23.34	43.23	516.32	
Average	**18.67**	**63.11**	**22.63**	**50.19**	**450.31**	**7204.96**
2018-11-01 0:00:00	16.49	54.41	22.54	38.57	488.88	
2018-11-02 0:00:00	16.75	59.93	21.98	43.67	464.80	
2018-11-03 0:00:00	17.79	75.61	22.03	55.60	466.48	
2018-11-04 0:00:00	18.88	77.82	22.07	61.09	300.16	
2018-11-05 0:00:00	19.31	83.36	22.31	65.67	299.04	
2018-11-06 0:00:00	18.31	81.28	22.18	63.92	505.12	
2018-11-07 0:00:00	17.86	92.99	22.45	69.10	465.36	
2018-11-08 0:00:00	13.33	85.26	21.21	56.25	485.52	
2018-11-09 0:00:00	13.71	73.86	20.47	48.54	500.64	
2018-11-10 0:00:00	15.36	75.04	20.31	52.69	484.96	
2018-11-11 0:00:00	17.61	80.64	20.54	63.95	355.60	
2018-11-12 0:00:00	15.70	81.51	20.21	61.56	285.04	
2018-11-13 0:00:00	15.50	65.98	20.06	49.81	483.28	
2018-11-14 0:00:00	15.19	72.70	19.70	52.45	478.80	
2018-11-15 0:00:00	15.75	84.08	20.03	61.23	502.88	
2018-11-16 0:00:00	14.88	87.52	19.62	64.84	487.76	
2018-11-17 0:00:00	15.41	71.17	18.96	55.78	535.36	
2018-11-18 0:00:00	12.90	87.90	18.12	62.65	300.16	
2018-11-19 0:00:00	13.14	76.50	17.92	56.09	266.56	
2018-11-20 0:00:00	14.72	77.59	18.03	60.45	1158.08	
2018-11-21 0:00:00	14.03	92.46	18.24	70.90	0.00	
2018-11-22 0:00:00	13.31	68.91	18.09	51.66	338.24	
2018-11-23 0:00:00	12.86	69.59	18.38	47.75	525.28	
2018-11-24 0:00:00	15.38	70.83	19.45	52.06	528.64	
2018-11-25 0:00:00	14.92	81.13	19.53	58.21	423.92	
2018-11-26 0:00:00	16.62	82.52	19.65	65.95	330.40	
2018-11-27 0:00:00	15.96	80.28	19.85	61.41	546.56	
2018-11-28 0:00:00	14.28	81.77	19.25	59.62	544.88	
2018-11-29 0:00:00	14.79	79.45	19.40	58.39	542.08	
2018-11-30 0:00:00	15.46	82.59	19.52	62.08	499.52	
Average	**15.54**	**77.82**	**20.07**	**57.73**	**453.13**	**13594.00**
2018-12-01 0:00:00	17.42	81.77	20.16	65.03	490.56	
2018-12-02 0:00:00	18.00	92.29	20.38	75.27	298.48	

2018-12-03 0:00:00	18.43	92.59	21.07	76.63	298.48	
2018-12-04 0:00:00	15.33	88.68	20.06	67.25	478.80	
2018-12-05 0:00:00	12.79	79.53	18.66	55.21	483.28	
2018-12-06 0:00:00	11.27	86.97	18.19	57.60	459.76	
2018-12-07 0:00:00	5.99	84.41	17.60	43.78	427.84	
2018-12-08 0:00:00	3.48	77.39	16.72	36.35	455.28	
2018-12-09 0:00:00	4.44	86.93	14.67	43.48	327.04	
2018-12-10 0:00:00	9.19	90.55	14.33	60.37	196.00	
2018-12-11 0:00:00	8.67	91.27	18.36	53.77	704.48	
2018-12-12 0:00:00	5.82	74.56	19.46	35.01	1289.68	
2018-12-13 0:00:00	5.59	64.35	14.34	35.84	895.44	
2018-12-14 0:00:00	7.23	66.90	13.82	41.17	927.92	
2018-12-15 0:00:00	9.05	78.37	13.99	51.54	906.64	
2018-12-16 0:00:00	8.05	78.25	13.85	54.09	378.00	
2018-12-17 0:00:00	8.88	65.36	16.83	42.14	290.08	
2018-12-18 0:00:00	10.07	68.09	15.72	45.29	950.32	
2018-12-19 0:00:00	12.06	69.64	18.02	46.28	766.08	
2018-12-20 0:00:00	11.76	84.60	16.01	61.83	542.64	
2018-12-21 0:00:00	12.49	89.20	20.54	53.79	503.44	
2018-12-22 0:00:00	12.74	96.30	17.91	66.98	505.12	
2018-12-23 0:00:00	10.99	75.16	15.57	56.15	382.48	
2018-12-24 0:00:00	9.89	69.13	15.51	48.87	290.64	
2018-12-25 0:00:00	10.81	80.15	15.29	57.29	519.68	
2018-12-26 0:00:00	9.69	92.25	15.70	65.21	519.68	
2018-12-27 0:00:00	6.77	74.82	14.62	48.43	664.72	
2018-12-28 0:00:00	3.17	59.08	13.29	34.90	1235.36	
2018-12-29 0:00:00	0.90	62.85	12.67	32.04	763.84	
2018-12-30 0:00:00	1.89	74.25	11.84	38.76	1092.00	
2018-12-31 0:00:00	3.56	80.56	16.62	36.65	266.56	
Average	**9.24**	**79.23**	**16.51**	**51.19**	**590.66**	**18310.32**
2019-01-01 0:00:00	4.18	66.65	11.65	41.43	244.16	
2019-01-02 0:00:00	5.24	66.62	18.45	31.08	249.20	
2019-01-03 0:00:00	7.23	73.85	15.02	42.33	1437.52	
2019-01-04 0:00:00	9.37	89.35	13.94	60.66	1445.36	
2019-01-05 0:00:00	8.13	94.18	13.86	63.87	1105.44	
2019-01-06 0:00:00	7.32	89.37	13.51	60.84	437.92	
2019-01-07 0:00:00	7.11	89.07	18.19	47.78	299.04	
2019-01-08 0:00:00	6.84	79.02	14.96	48.04	1138.48	
2019-01-09 0:00:00	5.25	85.59	13.77	49.11	864.64	
2019-01-10 0:00:00	6.72	94.34	13.60	57.57	893.76	
2019-01-11 0:00:00	7.87	95.77	13.66	62.76	719.60	
2019-01-12 0:00:00	6.83	85.80	13.43	59.21	779.52	
2019-01-13 0:00:00	6.43	78.34	13.13	52.16	693.84	
2019-01-14 0:00:00	7.27	82.02	16.26	46.86	253.12	
2019-01-15 0:00:00	7.56	81.32	17.38	45.78	666.96	
2019-01-16 0:00:00	4.73	63.29	17.86	33.46	599.76	
2019-01-17 0:00:00	5.03	63.10	17.89	31.11	3767.68	
2019-01-18 0:00:00	6.78	72.83	15.08	39.85	0.00	

2019-01-19 0:00:00	8.48	80.53	19.16	40.89	0.00	
2019-01-20 0:00:00	6.88	68.97	14.43	44.51	0.00	
2019-01-21 0:00:00	5.27	60.36	13.91	36.86	0.00	
2019-01-22 0:00:00	6.77	55.12	16.70	32.75	0.00	
2019-01-23 0:00:00	7.71	55.59	16.17	33.65	83.44	
2019-01-24 0:00:00	8.52	64.88	14.77	39.41	657.44	
2019-01-25 0:00:00	8.43	70.85	14.76	46.56	487.76	
2019-01-26 0:00:00	4.75	56.82	16.00	33.67	488.88	
2019-01-27 0:00:00	6.37	64.25	14.86	36.42	698.32	
2019-01-28 0:00:00	7.23	74.87	19.34	37.76	246.40	
2019-01-29 0:00:00	8.04	76.44	17.04	42.62	427.28	
2019-01-30 0:00:00	11.20	82.41	16.03	56.35	417.76	
2019-01-31 0:00:00	6.35	82.56	14.39	55.65	399.84	
Average	**6.96**	**75.62**	**15.46**	**45.52**	**629.13**	**19503.12**
2019-02-01 0:00:00	4.11	71.15	14.40	40.18	360.08	
2019-02-02 0:00:00	9.57	81.92	12.83	51.40	281.12	
2019-02-03 0:00:00	10.24	83.58	12.97	61.13	226.24	
2019-02-04 0:00:00	8.75	71.10	12.82	53.17	163.52	
2019-02-05 0:00:00	10.07	75.37	12.79	56.44	162.40	
2019-02-06 0:00:00	12.21	82.12	13.22	62.58	163.52	
2019-02-07 0:00:00	8.41	82.91	12.98	60.07	162.96	
2019-02-08 0:00:00	3.93	82.75	11.63	49.25	164.08	
2019-02-09 0:00:00	3.83	80.30	10.80	50.03	163.52	
2019-02-10 0:00:00	3.55	81.28	10.18	50.58	162.96	
2019-02-11 0:00:00	3.90	69.22	9.67	47.27	161.28	
2019-02-12 0:00:00	5.80	85.67	9.70	56.82	253.68	
2019-02-13 0:00:00	7.00	85.13	14.65	52.84	342.72	
2019-02-14 0:00:00	5.99	88.34	12.05	55.06	442.96	
2019-02-15 0:00:00	6.27	93.42	11.14	63.05	938.00	
2019-02-16 0:00:00	4.86	74.75	10.54	54.28	1192.24	
2019-02-17 0:00:00	6.13	65.11	10.58	48.23	896.00	
2019-02-18 0:00:00	6.32	90.22	16.18	47.32	314.16	
2019-02-19 0:00:00	7.62	84.22	16.32	48.99	1345.12	
2019-02-20 0:00:00	5.78	92.81	17.31	46.45	787.36	
2019-02-21 0:00:00	6.71	89.11	16.34	47.94	1418.48	
2019-02-22 0:00:00	5.70	87.18	15.20	48.58	1279.04	
2019-02-23 0:00:00	6.71	74.50	12.95	47.76	808.64	
2019-02-24 0:00:00	10.15	61.10	12.88	44.55	311.92	
2019-02-25 0:00:00	7.94	76.23	15.06	48.16	213.36	
2019-02-26 0:00:00	9.56	75.16	17.76	49.55	788.48	
2019-02-27 0:00:00	8.69	86.79	16.04	49.69	666.96	
2019-02-28 0:00:00	9.88	73.78	14.75	52.40	787.36	
Average	**7.13**	**80.19**	**13.35**	**51.56**	**534.22**	**14958.16**
2019-03-01 0:00:00	8.55	79.09	14.21	59.03	498.40	
2019-03-02 0:00:00	7.62	87.82	13.45	56.66	506.80	
2019-03-03 0:00:00	8.77	76.03	13.67	52.90	336.56	
2019-03-04 0:00:00	11.41	64.90	16.47	53.63	239.68	

2019-03-05 0:00:00	9.49	85.67	15.80	59.57	462.00	
2019-03-06 0:00:00	11.98	77.67	14.27	43.76	518.00	
2019-03-07 0:00:00	10.74	58.27	14.44	47.10	487.76	
2019-03-08 0:00:00	9.06	67.70	15.00	63.06	493.36	
2019-03-09 0:00:00	10.42	90.96	14.64	66.43	489.44	
2019-03-10 0:00:00	10.00	88.69	15.00	58.29	292.32	
2019-03-11 0:00:00	12.30	71.92	15.79	46.83	235.20	
2019-03-12 0:00:00	13.44	59.02	15.82	46.30	465.92	
2019-03-13 0:00:00	11.90	61.68	15.61	53.39	460.88	
2019-03-14 0:00:00	9.42	77.90	16.15	50.77	477.12	
2019-03-15 0:00:00	13.27	64.12	16.41	47.13	518.00	
2019-03-16 0:00:00	14.20	57.26	16.78	53.46	437.92	
2019-03-17 0:00:00	14.99	67.03	16.73	59.80	136.08	
2019-03-18 0:00:00	11.89	81.75	16.81	54.78	99.12	
2019-03-19 0:00:00	15.00	67.21	18.01	67.45	186.48	
2019-03-20 0:00:00	18.87	72.25	18.21	65.85	207.76	
2019-03-21 0:00:00	14.72	76.12	16.17	45.98	187.04	
2019-03-22 0:00:00	10.66	61.64	15.71	43.59	187.04	
2019-03-23 0:00:00	12.59	55.75	15.70	46.99	184.80	
2019-03-24 0:00:00	11.80	61.09	15.96	57.52	129.36	
2019-03-25 0:00:00	12.04	75.62	17.11	56.76	92.96	
2019-03-26 0:00:00	15.84	67.08	18.30	61.00	203.28	
2019-03-27 0:00:00	15.38	75.22	20.57	61.49	171.92	
2019-03-28 0:00:00	15.18	85.00	18.73	63.87	206.08	
2019-03-29 0:00:00	16.11	75.43	18.19	58.47	196.00	
2019-03-30 0:00:00	14.73	70.78	17.10	36.98	215.04	
2019-03-31 0:00:00	13.67	43.83	16.76	36.60	109.20	
Average	**12.45**	**71.11**	**16.24**	**54.05**	**304.24**	**9431.52**
2019-04-01 0:00:00	14.23	47.58	17.22	47.52	85.12	
2019-04-02 0:00:00	14.05	59.40	17.66	55.99	208.88	
2019-04-03 0:00:00	15.88	66.63	17.49	61.95	221.20	
2019-04-04 0:00:00	13.29	81.02	17.86	61.65	222.88	
2019-04-05 0:00:00	18.78	65.27	18.58	62.23	218.40	
2019-04-06 0:00:00	19.98	63.75	19.58	63.32	103.60	
2019-04-07 0:00:00	22.04	61.65	21.18	67.44	96.32	
2019-04-08 0:00:00	21.97	69.80	21.96	76.79	99.12	
2019-04-09 0:00:00	20.84	79.76	19.88	49.47	196.00	
2019-04-10 0:00:00	11.76	73.81	18.90	48.84	200.48	
2019-04-11 0:00:00	12.48	67.57	18.60	49.03	188.72	
2019-04-12 0:00:00	14.43	62.24	18.36	54.37	202.16	
2019-04-13 0:00:00	16.77	64.26	18.60	61.08	206.08	
2019-04-14 0:00:00	16.76	69.99	18.72	45.27	91.28	
2019-04-15 0:00:00	16.46	56.32	18.52	55.82	96.88	
2019-04-16 0:00:00	16.50	65.59	19.39	64.48	184.80	
2019-04-17 0:00:00	19.00	71.50	20.68	65.99	148.40	
2019-04-18 0:00:00	22.77	65.68	21.74	74.55	174.16	
2019-04-19 0:00:00	22.19	76.16	21.60	75.19	186.48	
2019-04-20 0:00:00	21.38	76.67	21.77	79.49	152.88	

2019-04-21 0:00:00	20.94	84.86	21.97	80.71	94.08	
2019-04-22 0:00:00	19.23	94.06	22.92	80.23	94.08	
2019-04-23 0:00:00	22.97	82.87	23.45	78.71	198.80	
2019-04-24 0:00:00	22.34	83.58	23.08	70.29	183.12	
2019-04-25 0:00:00	20.92	77.45	21.81	56.36	206.64	
2019-04-26 0:00:00	15.15	75.15	20.30	49.23	198.80	
2019-04-27 0:00:00	15.78	63.46	20.59	66.13	205.52	
2019-04-28 0:00:00	17.27	82.50	20.92	71.61	100.80	
2019-04-29 0:00:00	17.41	87.68	20.07	67.40	180.32	
2019-04-30 0:00:00	15.70	85.59	20.03	61.98	172.48	
Average	**17.98**	**72.06**	**20.11**	**63.44**	**163.95**	**4918.48**
2019-05-01 0:00:00	18.83	68.79	20.28	48.45	177.52	
2019-05-02 0:00:00	20.29	51.22	20.61	44.55	83.44	
2019-05-03 0:00:00	21.62	47.27	21.09	41.27	78.96	
2019-05-04 0:00:00	22.73	41.81	21.77	57.86	76.16	
2019-05-05 0:00:00	20.93	64.90	21.20	48.72	81.76	
2019-05-06 0:00:00	17.84	57.46	21.17	36.49	171.92	
2019-05-07 0:00:00	17.69	42.18	21.17	46.45	182.56	
2019-05-08 0:00:00	19.10	52.24	22.07	52.41	179.20	
2019-05-09 0:00:00	21.04	60.65	22.60	56.35	175.28	
2019-05-10 0:00:00	22.31	60.58	23.25	55.36	155.68	
2019-05-11 0:00:00	24.24	57.81	23.65	55.33	196.56	
2019-05-12 0:00:00	23.40	58.20	23.30	58.96	102.48	
2019-05-13 0:00:00	19.96	70.78	23.04	61.74	117.60	
2019-05-14 0:00:00	19.94	73.76	22.87	71.55	195.44	
2019-05-15 0:00:00	20.04	85.93	23.22	76.12	174.72	
2019-05-16 0:00:00	21.94	84.10	23.87	79.64	216.72	
2019-05-17 0:00:00	23.32	84.76	23.66	74.27	221.76	
2019-05-18 0:00:00	22.52	77.94	23.32	70.84	226.80	
2019-05-19 0:00:00	21.49	79.97	23.76	74.06	119.28	
2019-05-20 0:00:00	21.01	64.23	23.68	48.13	106.40	
2019-05-21 0:00:00	16.77	63.75	23.81	37.77	165.76	
2019-05-22 0:00:00	16.76	61.65	24.98	43.86	170.24	
2019-05-23 0:00:00	16.46	69.80	25.78	48.59	201.60	
2019-05-24 0:00:00	16.50	79.76	25.99	45.67	213.36	
2019-05-25 0:00:00	19.00	73.81	25.41	64.17	384.16	
2019-05-26 0:00:00	22.77	67.57	24.88	76.73	278.32	
2019-05-27 0:00:00	22.19	62.24	25.14	71.79	117.04	
2019-05-28 0:00:00	21.38	64.26	24.65	41.57	343.28	
2019-05-29 0:00:00	20.94	69.99	25.07	40.75	189.84	
2019-05-30 0:00:00	19.23	56.32	24.45	44.39	183.12	
2019-05-31 0:00:00	22.97	65.59	22.60	56.35	206.64	
Average	**20.49**	**65.14**	**23.30**	**55.81**	**177.21**	**5493.6**
2019-06-01 0:00:00	18.03	67.99	19.48	50.44	349.44	
2019-06-02 0:00:00	22.09	53.02	22.41	40.97	189.28	
2019-06-03 0:00:00	20.62	46.27	20.09	43.33	208.32	
2019-06-04 0:00:00	21.93	41.01	20.97	60.07	146.72	

2019-06-05 0:00:00	22.73	66.70	23.00	44.90	213.92	
2019-06-06 0:00:00	16.84	56.46	20.17	38.30	338.24	
2019-06-07 0:00:00	16.89	41.38	20.37	48.28	359.52	
2019-06-08 0:00:00	20.90	54.04	23.87	48.46	352.80	
2019-06-09 0:00:00	20.04	59.65	21.60	58.96	344.96	
2019-06-10 0:00:00	21.51	59.78	22.45	57.33	333.76	
2019-06-11 0:00:00	26.04	59.61	25.45	51.42	387.52	
2019-06-12 0:00:00	22.40	57.20	22.30	61.60	255.36	
2019-06-13 0:00:00	19.16	69.98	22.24	63.97	229.60	
2019-06-14 0:00:00	21.74	75.56	24.67	66.33	385.28	
2019-06-15 0:00:00	19.04	84.93	22.22	79.55	343.84	
2019-06-16 0:00:00	21.14	83.30	23.07	82.41	444.64	
2019-06-17 0:00:00	25.12	86.56	25.46	69.02	437.92	
2019-06-18 0:00:00	21.52	76.94	22.32	74.01	448.00	
2019-06-19 0:00:00	20.69	79.17	22.96	76.64	344.96	
2019-06-20 0:00:00	22.81	66.03	25.48	44.73	207.20	
2019-06-21 0:00:00	15.77	62.75	22.81	39.42	325.92	
2019-06-22 0:00:00	15.96	60.85	24.18	45.31	334.88	
2019-06-23 0:00:00	18.26	71.60	27.58	45.42	397.60	
2019-06-24 0:00:00	15.50	78.76	24.99	47.50	421.12	
2019-06-25 0:00:00	18.20	73.01	24.61	66.26	762.72	
2019-06-26 0:00:00	24.57	69.37	26.68	71.56	551.04	
2019-06-27 0:00:00	21.19	61.24	24.14	74.76	228.48	
2019-06-28 0:00:00	20.58	63.46	23.85	42.96	708.96	
2019-06-29 0:00:00	22.74	71.79	26.87	38.02	486.08	
2019-06-30 0:00:00	18.23	55.32	23.45	46.28	416.64	
Average	**20.41**	**65.12**	**23.32**	**55.94**	**365.16**	**10954.72**
2019-07-01 0:00:00	27.34	57.99	23.79	41.31	127.68	
2019-07-02 0:00:00	28.80	43.67	24.12	38.07	365.12	
2019-07-03 0:00:00	31.13	39.11	25.60	34.00	390.88	
2019-07-04 0:00:00	32.24	34.89	26.28	47.93	484.40	
2019-07-05 0:00:00	30.44	53.40	25.71	40.17	462.56	
2019-07-06 0:00:00	27.35	45.87	25.68	30.08	390.88	
2019-07-07 0:00:00	27.20	33.61	25.68	38.30	146.16	
2019-07-08 0:00:00	28.61	42.26	26.58	43.52	100.24	
2019-07-09 0:00:00	30.55	49.94	27.11	46.98	390.88	
2019-07-10 0:00:00	31.82	50.39	27.76	46.36	462.56	
2019-07-11 0:00:00	34.75	47.10	29.16	44.88	407.68	
2019-07-12 0:00:00	33.91	47.11	28.81	47.68	312.48	
2019-07-13 0:00:00	30.47	55.47	28.55	49.83	96.32	
2019-07-14 0:00:00	30.45	57.80	28.38	57.66	127.68	
2019-07-15 0:00:00	30.55	67.40	28.73	61.52	365.12	
2019-07-16 0:00:00	32.45	67.22	29.38	64.71	390.88	
2019-07-17 0:00:00	33.83	68.56	29.17	60.24	484.40	
2019-07-18 0:00:00	33.03	62.62	28.83	57.30	462.56	
2019-07-19 0:00:00	32.00	63.65	29.27	60.12	400.40	
2019-07-20 0:00:00	31.52	50.89	29.19	39.04	144.48	
2019-07-21 0:00:00	27.28	47.98	29.32	30.67	554.40	

2019-07-22 0:00:00	27.27	46.40	30.49	35.93	767.20	
2019-07-23 0:00:00	26.97	52.29	31.29	40.04	678.16	
2019-07-24 0:00:00	27.01	59.79	31.50	37.68	852.88	
2019-07-25 0:00:00	29.51	57.22	30.92	52.74	520.24	
2019-07-26 0:00:00	33.28	54.41	30.39	62.82	641.76	
2019-07-27 0:00:00	32.70	49.86	30.65	58.89	146.16	
2019-07-28 0:00:00	31.89	51.09	30.16	33.97	100.24	
2019-07-29 0:00:00	31.45	55.41	30.58	33.40	837.20	
2019-07-30 0:00:00	29.74	43.77	29.96	36.23	794.08	
2019-07-31 0:00:00	33.48	52.90	28.11	45.31	898.80	
Average	**30.61**	**51.94**	**28.42**	**45.72**	**429.18**	**13304.48**
2019-08-01 0:00:00	29.34	53.22	25.79	38.10	656.32	
2019-08-02 0:00:00	30.80	40.29	26.12	35.15	517.44	
2019-08-03 0:00:00	32.13	37.67	26.60	32.72	792.96	
2019-08-04 0:00:00	33.24	33.66	27.28	46.17	107.52	
2019-08-05 0:00:00	31.44	51.38	26.71	38.67	678.16	
2019-08-06 0:00:00	28.35	43.90	26.68	28.95	543.20	
2019-08-07 0:00:00	28.20	32.17	26.68	36.86	576.80	
2019-08-08 0:00:00	29.61	40.55	27.58	41.94	567.28	
2019-08-09 0:00:00	31.55	48.06	28.11	45.31	656.88	
2019-08-10 0:00:00	32.82	48.58	28.76	44.75	162.40	
2019-08-11 0:00:00	34.75	47.10	29.16	44.88	111.44	
2019-08-12 0:00:00	33.91	47.11	28.81	47.68	705.04	
2019-08-13 0:00:00	30.47	55.47	28.55	49.83	539.84	
2019-08-14 0:00:00	30.45	57.80	28.38	57.66	678.16	
2019-08-15 0:00:00	30.55	67.40	28.73	61.52	594.16	
2019-08-16 0:00:00	32.45	67.22	29.38	64.71	550.48	
2019-08-17 0:00:00	33.83	68.56	29.17	60.24	458.64	
2019-08-18 0:00:00	33.03	62.62	28.83	57.30	270.48	
2019-08-19 0:00:00	31.00	66.10	28.27	62.25	773.36	
2019-08-20 0:00:00	30.52	52.88	28.19	40.43	814.80	
2019-08-21 0:00:00	26.28	50.23	28.32	31.75	727.44	
2019-08-22 0:00:00	26.27	48.58	29.49	37.15	669.20	
2019-08-23 0:00:00	25.97	54.79	30.29	41.36	513.52	
2019-08-24 0:00:00	26.01	62.64	30.50	38.92	554.40	
2019-08-25 0:00:00	28.51	59.65	29.92	54.50	141.12	
2019-08-26 0:00:00	32.28	56.40	29.39	64.96	1033.20	
2019-08-27 0:00:00	31.70	51.73	29.65	60.87	750.40	
2019-08-28 0:00:00	30.89	53.06	29.16	35.14	1140.72	
2019-08-29 0:00:00	29.45	59.94	28.58	35.74	542.64	
2019-08-30 0:00:00	27.74	47.62	27.96	38.82	498.96	
2019-08-31 0:00:00	31.48	56.89	26.11	48.78	222.88	
Average	**30.49**	**52.36**	**28.29**	**45.91**	**566.12**	**17549.84**
2019-09-01 0:00:00	27.34	57.99	23.79	41.31	183.12	
2019-09-02 0:00:00	28.80	43.67	24.12	38.07	652.40	
2019-09-03 0:00:00	30.13	40.67	24.60	35.38	369.60	
2019-09-04 0:00:00	31.24	36.22	25.28	49.83	623.84	

2019-09-05 0:00:00	28.44	57.95	23.71	43.56	761.60	
2019-09-06 0:00:00	25.35	50.37	23.68	32.62	634.48	
2019-09-07 0:00:00	25.20	36.94	23.68	41.53	491.68	
2019-09-08 0:00:00	26.61	46.18	24.58	47.06	216.72	
2019-09-09 0:00:00	28.55	54.19	25.11	50.72	841.12	
2019-09-10 0:00:00	29.82	54.45	25.76	49.96	890.40	
2019-09-11 0:00:00	31.75	52.39	26.16	50.02	1029.28	
2019-09-12 0:00:00	29.91	54.67	24.81	55.37	867.44	
2019-09-13 0:00:00	26.47	65.80	24.55	57.95	503.44	
2019-09-14 0:00:00	26.45	68.57	24.38	67.12	515.76	
2019-09-15 0:00:00	26.55	79.91	24.73	71.48	556.08	
2019-09-16 0:00:00	28.45	78.68	25.38	74.91	716.24	
2019-09-17 0:00:00	29.83	79.60	25.17	69.81	810.32	
2019-09-18 0:00:00	28.03	76.22	23.83	69.32	787.36	
2019-09-19 0:00:00	27.00	78.11	24.27	72.51	597.52	
2019-09-20 0:00:00	26.52	62.71	24.19	47.11	695.52	
2019-09-21 0:00:00	22.28	61.86	24.32	36.98	266.00	
2019-09-22 0:00:00	22.27	59.83	25.49	42.98	271.60	
2019-09-23 0:00:00	21.97	67.70	26.29	47.65	349.44	
2019-09-24 0:00:00	21.01	82.20	25.50	46.55	358.96	
2019-09-25 0:00:00	23.51	75.77	24.92	65.44	467.60	
2019-09-26 0:00:00	27.28	69.06	24.39	78.28	350.56	
2019-09-27 0:00:00	26.70	63.65	24.65	73.22	380.24	
2019-09-28 0:00:00	25.89	65.77	24.16	42.41	257.60	
2019-09-29 0:00:00	24.45	75.35	23.58	43.32	442.40	
2019-09-30 0:00:00	22.74	61.05	22.96	47.27	464.80	
Average	**26.69**	**61.92**	**24.60**	**52.99**	**545.10**	**16353.12**
2019-10-01 0:00:00	22.34	74.70	18.79	52.30	225.12	
2019-10-02 0:00:00	23.80	55.28	19.12	48.02	220.64	
2019-10-03 0:00:00	25.13	50.77	19.60	44.41	221.76	
2019-10-04 0:00:00	26.24	44.75	20.28	62.12	193.76	
2019-10-05 0:00:00	23.44	73.66	18.71	55.20	178.08	
2019-10-06 0:00:00	20.35	66.78	18.68	41.35	180.88	
2019-10-07 0:00:00	20.20	49.09	18.68	52.64	169.12	
2019-10-08 0:00:00	21.61	60.07	19.58	59.07	315.28	
2019-10-09 0:00:00	23.55	68.80	20.11	63.33	358.40	
2019-10-10 0:00:00	23.82	71.81	19.76	65.13	399.84	
2019-10-11 0:00:00	25.75	67.53	20.16	64.91	388.08	
2019-10-12 0:00:00	24.91	68.40	19.81	69.34	333.76	
2019-10-13 0:00:00	21.47	85.79	19.55	72.77	269.36	
2019-10-14 0:00:00	21.45	89.41	19.38	84.43	416.08	
2019-10-15 0:00:00	20.55	90.75	18.73	94.38	397.60	
2019-10-16 0:00:00	22.45	95.73	19.38	98.10	386.96	
Average	**22.94**	**69.58**	**19.39**	**64.22**	**290.92**	**4654.72**
Total						**156,231.04**

Internal meter for typical building C1B1

Internal meter for typical building C2B1

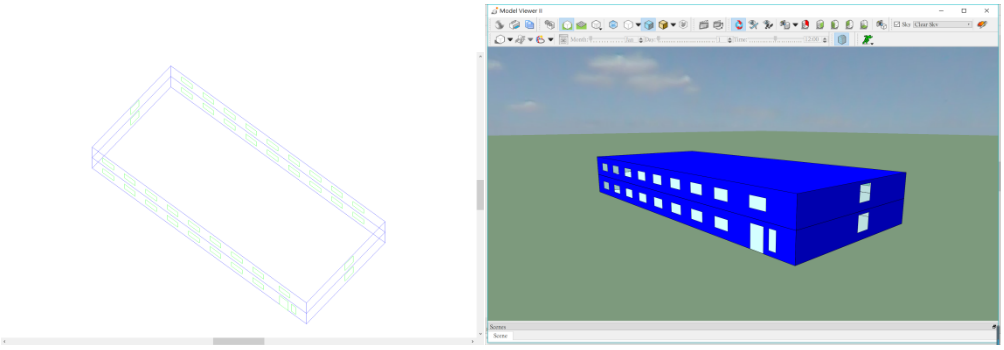
External meter for typical building C1B1

External meter for typical building C2B1

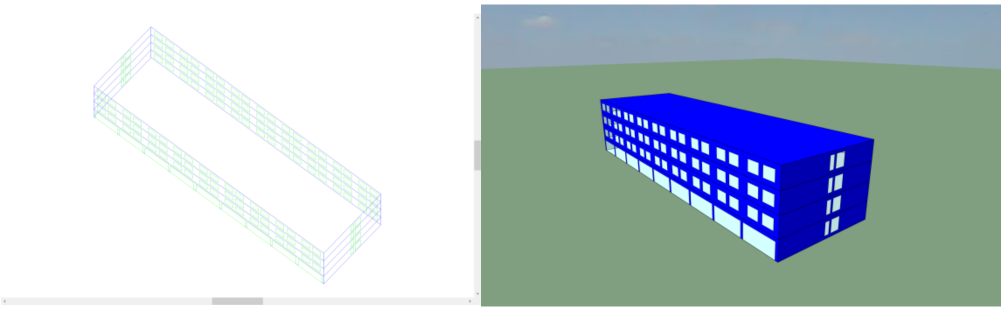
Fig. S1. Location of installed measuring meters in the typical buildings: C1B1 and C2B1

Table S5. Proposed prototype models for IES-VE software simulation

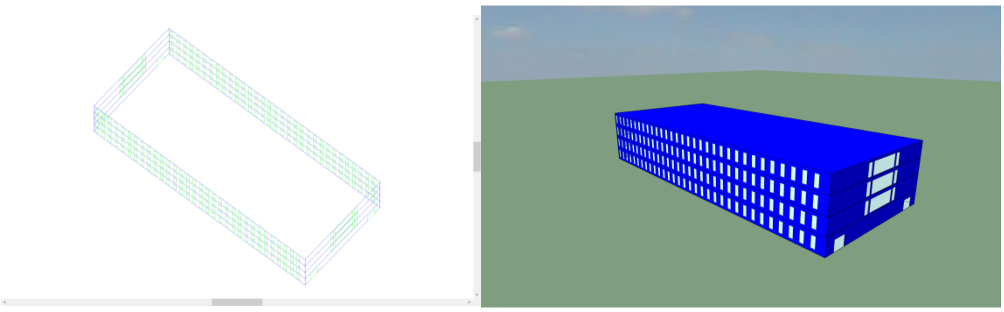
C1B1



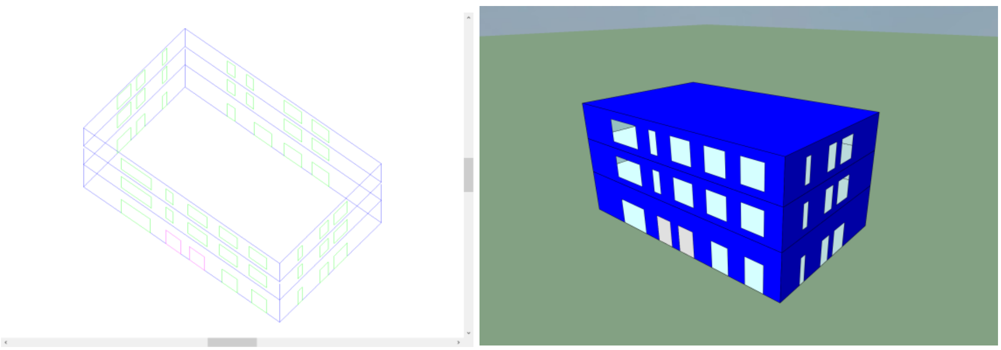
C1B2



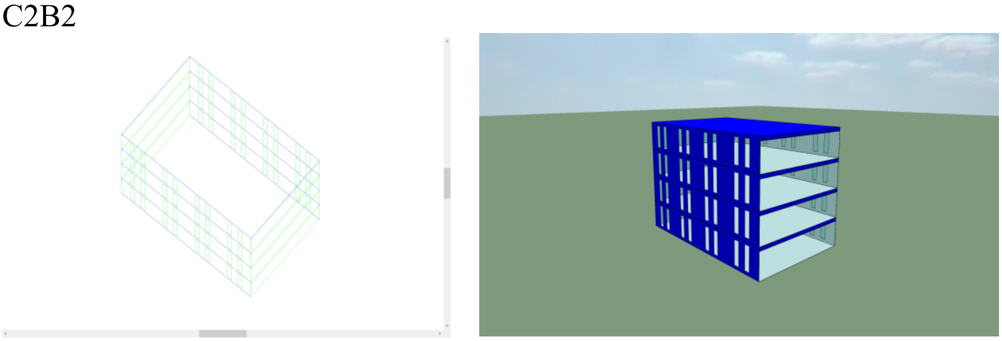
C1B3



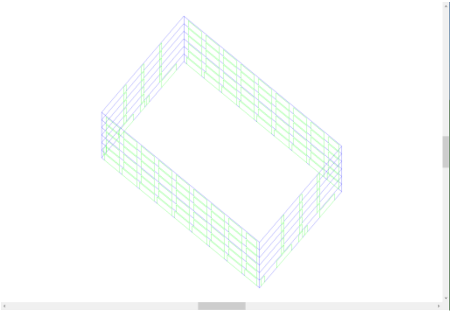
C2B1

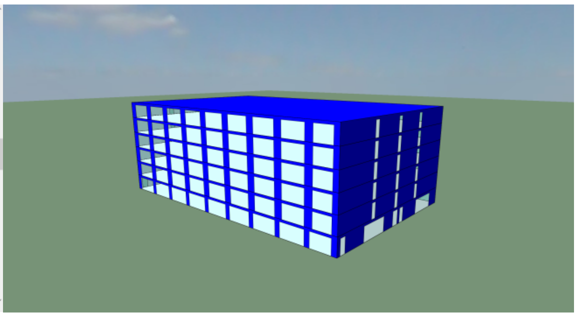


C2B2

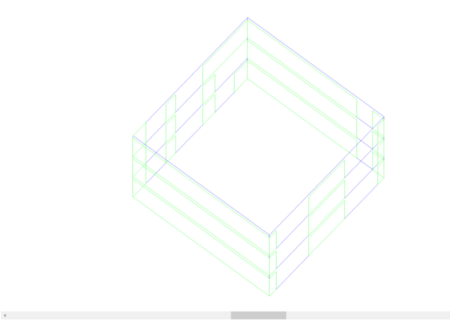


C2B3





C2B4



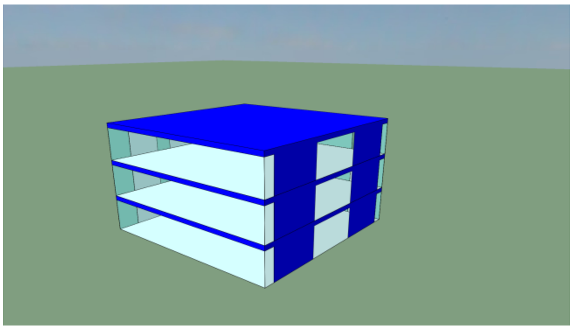
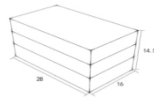
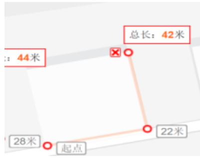
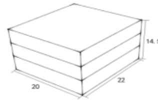
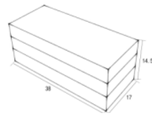
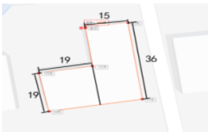
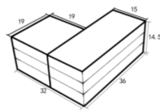
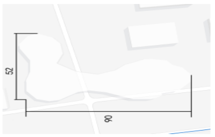
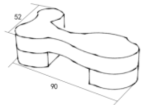
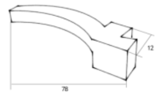
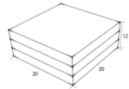
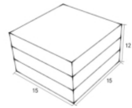
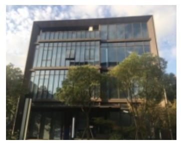
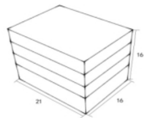
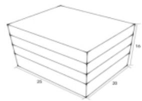
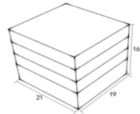
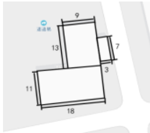
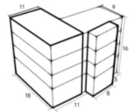
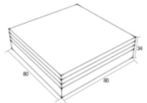
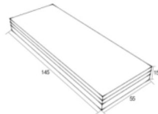
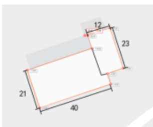
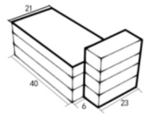
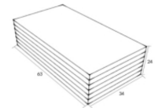
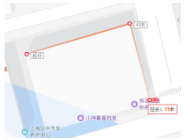
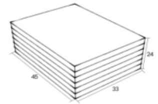
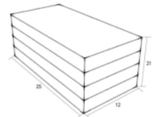


Table S6. C2 summary of selected low-rise buildings built within 2006-2015 (All dimensions are in metric units).

Office park name	Hong Xing International Square								
Building number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
1.3.5.6.7.8.9.10.12.14.15.16.18.19.20.21.22.23		28	16	14.5	3	1344			18
2.4		22	20	14.5	3	1320			2
24.25.26.27.28.29.30.31		38	17	14.5	3	1938			8
13.17		36	32	14.5	3	2748			2
11		90	52	14.5	3	2575			1

32		78	12	14.5	2	1550			1
Office park name	Pu Jiang Yi You Office Park								
Building number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
1.2		20	20	12	4	1600			2
3.4.5.6.7.8.9.10.11.12.13.14.15.16.17.18		15	15	12	4	900			16
Office park name	CIFI Pu Jiang International Square								
Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
1.4.5.6.19		21	16	16	4	1344			5
2.3.12.13.17.18.22.23.27.28		25	20	16	4	2000			10

7.8.9.11.14.15.16.20.21.24.25.26.29.30		21	19	16	4	1596			14
10		24	18	16	4	1344			1
Office park name	Pu Jiang Science and Technology Park								
Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
1.3		80	80	20	4	25600			2
4		145	55	15	3	23925			1
5		40	23	15	3	3117			1
Office park name	Vanke Zao City								

Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
1.2.5.6		63	34	24	6	12852			4
3.4.7		45	33	24	6	8910			3
Office park name	Vanke VMO Park								
Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
1.2.3.4.13.14.15 . 16.17.18.19.20.21 .22		25	12	21	4	1200			12

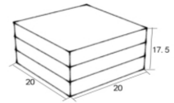
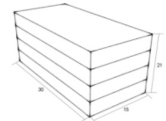
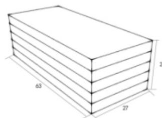
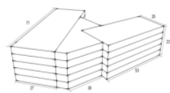
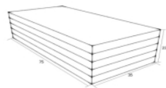
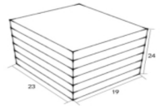
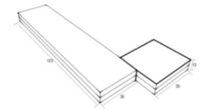
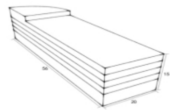
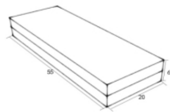
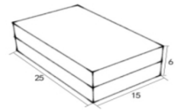
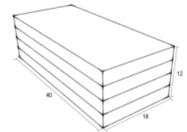
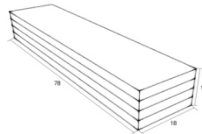
5		20	20	17.5	3	1200			1
4.5.6.7.8.9.10.11.12		30	15	21	4	1800			9

Table S7. C1 summary of selected low-rise buildings built within before 2005 (all dimensions are in metric units).

Office park name	Cao He Jing Office Park								
Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
2.3.4.5.6.7.8.9.10.11.12		63	27	23	5	8550			11
1		71	27	23	5	21225			1
13		75	35	23	5	13125			1

Office park name	Fawkes Chain Business Building (Hong Mei South Road)								
Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
1		23	19	24	6	2622			1
2		123	30	13	2	9970			1
Office park name	Fawkes Chain Business Building (Chun Shen Road)								
Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
3.4		56	20	15	5	2240			2
1		55	20	6	2	5500			1

2		25	15	6	2	750			1
Office park name	Fawkes Chain Business Building (Dou Zhuang Road)								
Building Number		Length	Width	Height	Number of Floors	Floor Area	Actual photos	Simplified building model	Amount
1		40	18	12	4	2889			1
2.3.4		78	18	12	4	5616			3